The WELDING JOURNAL

SEPTEMBER 1954

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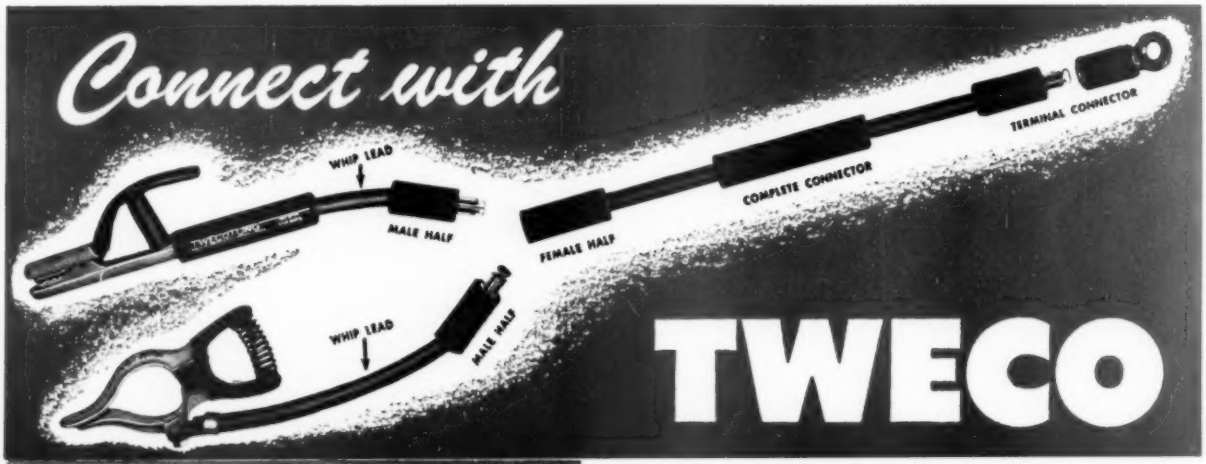

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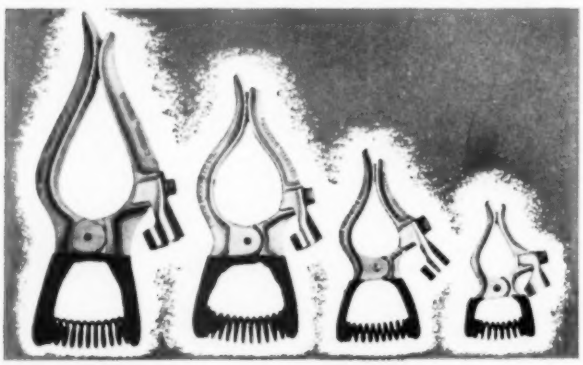

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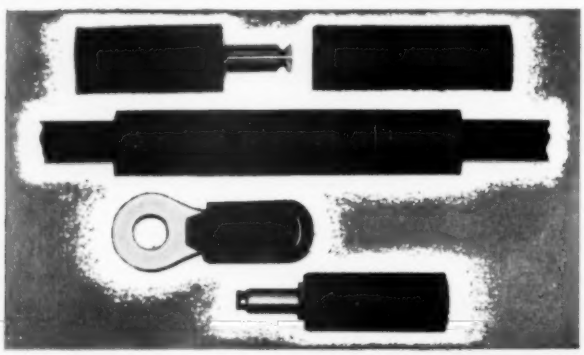

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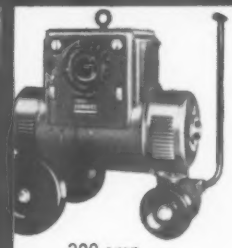

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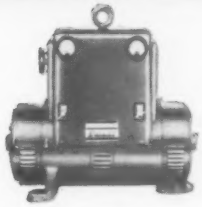

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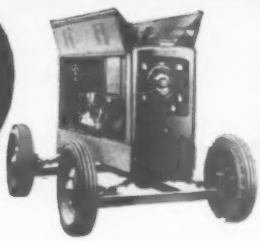

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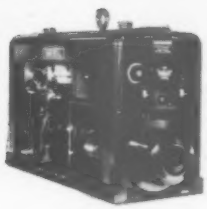

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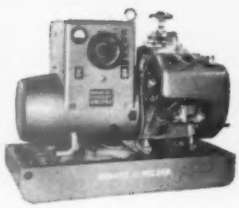

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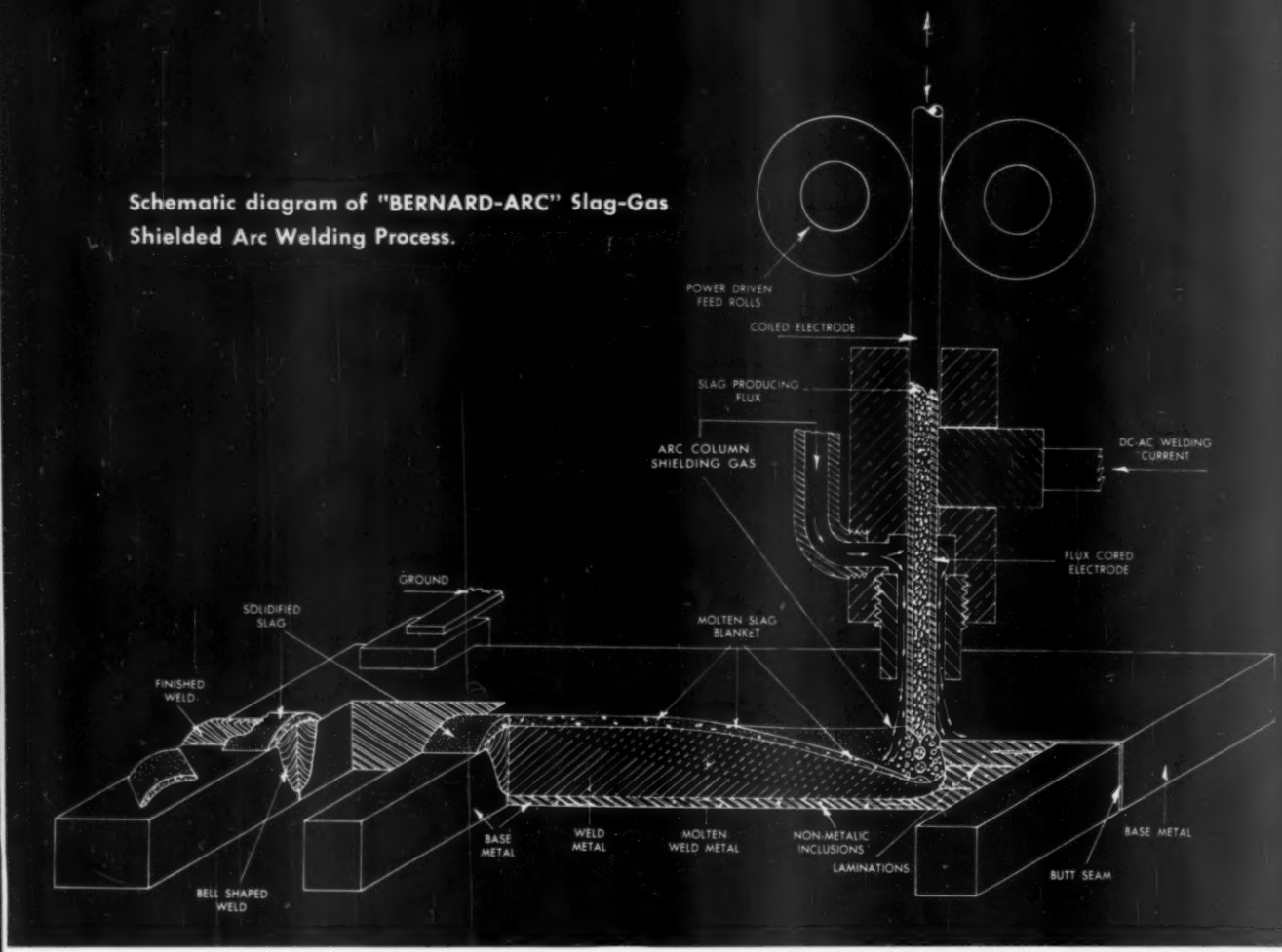

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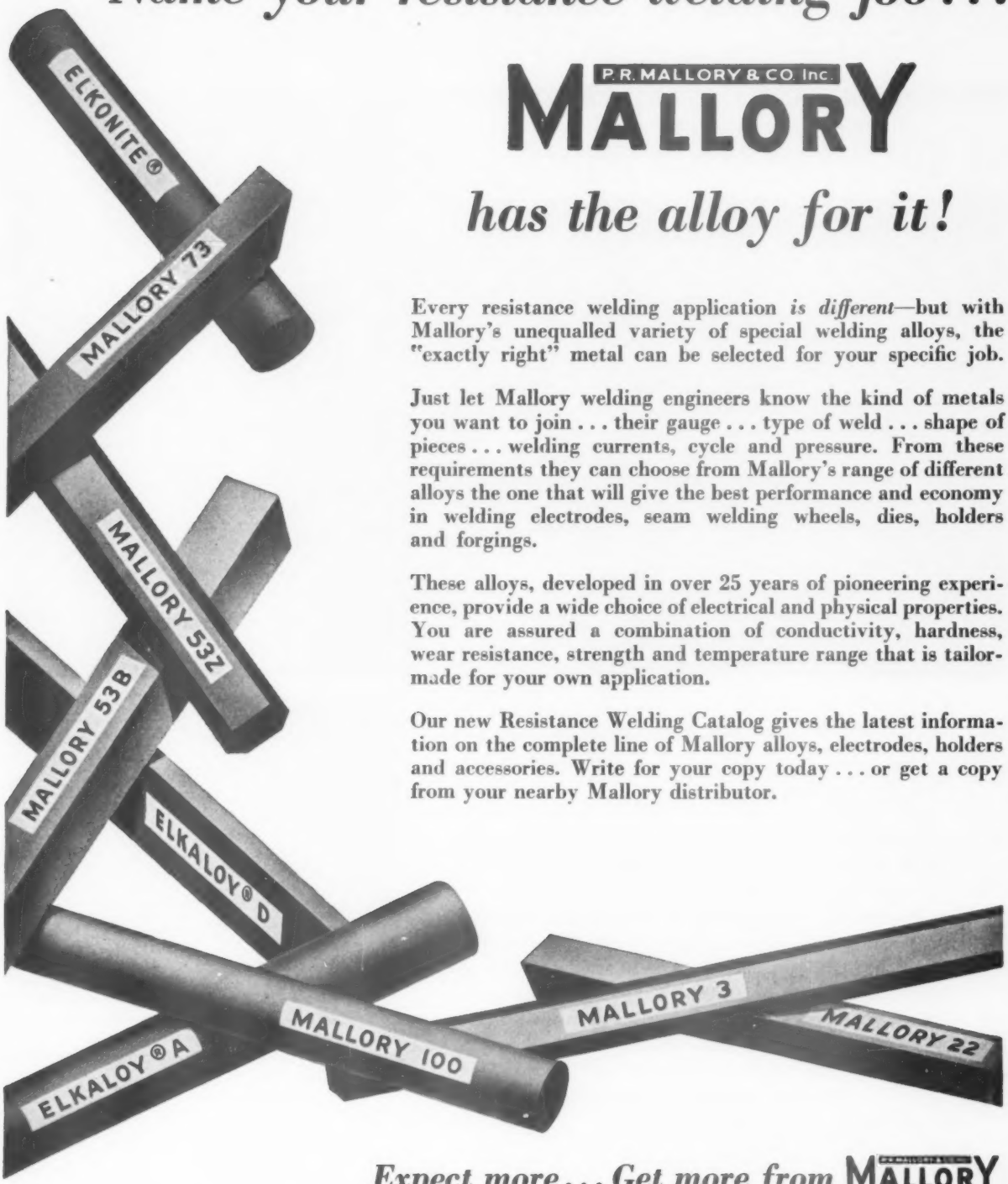

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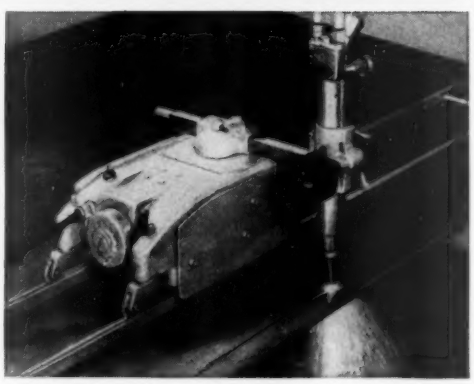

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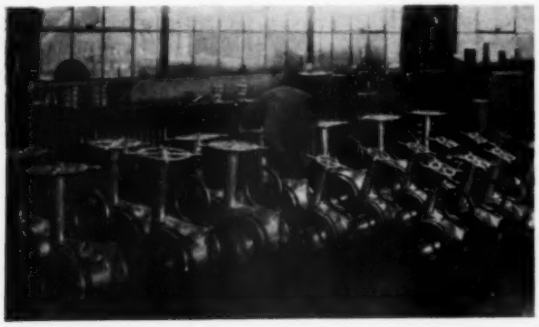

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The WELDING JOURNAL

volume 33 September 1954 number 9

Manually Guided Submerged-Arc Welding

Manual submerged-arc welding can be used economically on joints of irregular shapes, relatively inaccessible joints and where flexibility is required

by R. A. Kubli

INTRODUCTION

SUBMERGED-arc or submerged-melt welding refers to the process of electric welding beneath a blanket of granular welding composition. The granular welding composition provides the special operating characteristics that distinguish the process. It permits the use of higher current densities on welding electrodes than could be used successfully in earlier methods and performs the function of cleansing the weld puddle and protecting it from atmospheric contamination. The melted base metal and welding electrode metal are completely submerged beneath the melted welding composition; hence the name "submerged melt welding."

A manual submerged-melt welding installation has the same elements found in a completely mechanized installation except that a travel carriage is not used. The function of the travel carriage is taken over by the operator whose function during welding is to guide the welding head over the seam at a reasonably constant speed.

Manual submerged-melt welding equipment combines the flexibility of hand operation with the well-known advantages of quality and economy of submerged-melt welding. It provides the manual welding arc with a tool capable of producing high quality welds at low cost, with greater operator comfort, and generally with less skill than required with coated electrode open-arc welding.

SCOPE OF THE PROCESS

Manual submerged-melt welding has the same wide range of application to various materials as does the fully mechanized version of the process. Low- and medium-carbon steels, low-alloy steels, certain stainless steels and copper and nickel base alloys can be welded by this process. However, the vast majority of present applications are concerned with carbon steel welding such as is usually found in a structural fabrication, maintenance or general production work. Manual submerged-melt welding fits into the production picture when joints are of such irregular shape as to make it difficult or disproportionately expensive to set up for mechanized welding. Manual submerged-melt welding is also used for inaccessible joints which otherwise could not be reached except with short coated electrodes. In structural fabrication a variety of short joints occur at separated points. This requires the flexibility of manual welding as opposed to the "semi-permanency" of even the most portable machines.

Manual submerged-melt welding is almost always used in the horizontal or nearly horizontal position due to the fluidity of the molten and granular materials.

Fig. 1 The Unionmelt portable flexible welding machine

R. A. Kubli is with the Linde Air Products Co., New York, N Y.

Presented at the AWS National Spring Meeting held in Buffalo, N. Y., May 4–7, 1954.

Applications include flat butt welds, flat and horizontal fillet welds, lap fillet welds, plug welds and variations of these types of joints. The high deposition rate of the process can be used to the most advantage in fillet welding.

COMPARISON WITH MANUAL COATED ELECTRODE WELDING

Manual submerged-melt welding competes directly with coated electrode welding offering many advantages and correspondingly few disadvantages. A few comparisons between the two processes may be interesting.

1. *High deposition rate* is the most striking advantage of submerged-melt welding. The semiautomatic operation of the equipment and its automatically controlled wire feeding allow the operator to handle high currents for greater lengths of time. Therefore, even if the rate of metal deposition with a given current were equal for both open-arc and submerged-melt welding, the amount of metal deposited by an operator in a given length of time would be much greater for manual submerged-melt welding. For example, under frequently used conditions, the melting rate for submerged-melt welding would be 0.5 lb per 1000 amp per minute. Since available apparatus will readily handle 600 amp an operator working 60% of the time could deposit approximately 11 lb per hour. Contrast this figure with a maximum of 3.8 lb per hour for a $^1/_4$-in. diam, Class E-6010 electrode, working at 280 amp. Currents up to 800 amp can be used on certain submerged-melt welding applications where the metal is deposited at the rate of 14.6 lb per hour.

2. *Material cost* per pound of deposited metal is a common basis of comparison in determining the relative cost or a welding operation. It should be remembered, however, that such a figure is of limited value in comparing submerged-melt welding with other methods. It cannot properly be used except for such work as casting repair or surface build-up where the amount of metal to be deposited is determined by requirements other than those of making a joint. Manual submerged-melt welding materials cost slightly more per unit of wire purchased than do coated electrodes. The cost per pound of welding wire deposited by submerged-melt welding comes to approximately $0.25 with welding wire cost taken at $0.13 per pound and welding composition cost taken at $0.10 per pound; the usual ratio of welding composition to wire is assumed to be 1.2 to 1.0. Coated electrodes of the E-6010 class usually cost approximately $0.13 per pound, however, this figure includes approximately 15% in coating, making the metal cost approximately $0.15 per pound. Spatter and stub end losses may increase this figure to $0.20 to $0.22 per pound for coated electrode metal usefully deposited. With submerged-melt welding there is no loss in metal transfer through spatter. This material cost differential is more than made up in quality and speed of submerged melt welding. For the usual seam welding with submerged-melt welding, the amount of metal required to make the joint is less than with coated electrodes. The material cost per unit length of equivalent strength joints with submerged-melt welding is therefore actually lower than the cost per pound comparison indicates.

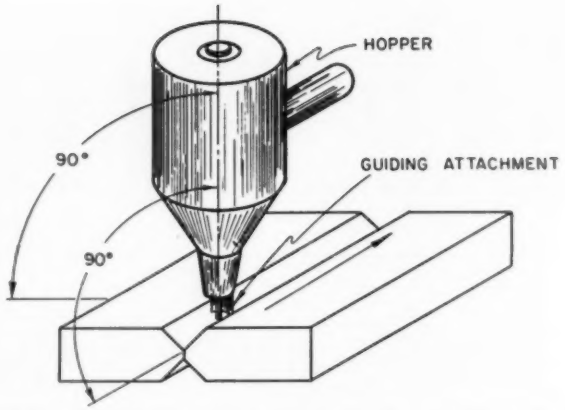
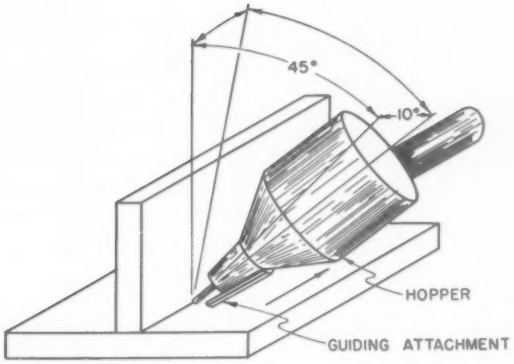


Fig. 2 Recommended position of the nozzle for welding flat seams

3. *Miscellaneous cost factors.* Several miscellaneous factors affecting costs must also be considered. Removal of the fused slag from the weld surface is an important operation which must be done before additional passes are made or further processing is started. Removal of the fused submerged melt welding composition is relatively simple and with a properly made weld, the slag is practically self-removing. In multipass welding where the fused material is somewhat more difficult to remove, the amount of interpass cleaning is reduced because higher currents are used and fewer passes are required. Reduction in the number of passes is, of course, an economy in itself. Stub loss is practically eliminated with submerged-melt welding because the wire is continually fed from 25- or 65-lb coils. Loss of the amount of wire remaining in the flexible conduit might be called a stub loss, but it is on the order of only 1% of the total weight of the coil.

4. *Welding current flexibility.* Manual submerged-melt welding can be accomplished with either a-c, conventional d-c or constant-potential d-c power supplies. However, constant potential power is recommended only when welding currents are close to the maximum output of the constant potential equipment. Under these conditions, it provides better starting and handling characteristics than conventional power supplies. Equipment is available which can be used with any of the available types of power supply without alteration. This flexibility may be particularly attractive in those shops where investment in special purpose units cannot be justified.

5. *Operator considerations.* Operator considerations have both tangible and intangible effects on the cost or success of a welding process. Manual sub-



FILLET WELDING USING THE DRAG TECHNIQUE

Fig. 3 Recommended position of the nozzle for making flat fillet welds

Fig. 4 Boiler fabrication is speeded by manual submerged-melt welding

merged-melt welding has several characteristics which make it attractive to an operator. There is no visible arc or spatter and therefore it is unnecessary to wear the heavy welding helmet and special clothing for protection from arc radiation. No protection is used by many operators; but safety goggles, preferably tinted to guard against an occasional flash, are recommended. The use of such goggles also offers protection from open arcs that may be operating in the vicinity on other kinds of welding. There is less radiated heat to make the operator uncomfortable even though high currents are used in submerged melt welding. There is also less fuming than with coated electrodes.

With reasonable manual dexterity, an operator can learn to produce work of the highest quality in a relatively short time. Manual submerged melt welding is a semiautomatic process whereas coated electrode welding depends largely on operator skill. The welding control unit keeps the end of the welding wire at a constant distance from the work regardless of unavoidable movements of the welding head in the operator's hand. The operator's only task is to guide the head along the seam while maintaining a reasonable uniform height of granular welding composition.

6. *Weld quality.* Radiographic examination of manual submerged-melt welds shows them to be equal in quality to fully mechanized submerged-melt welds. Generally, they are superior to welds obtained with coated electrodes. The welds easily pass code requirements and standards, such as the ASME boiler code for unfired pressure vessels. Satisfactory welds can be made on rusted plate or plates containing moderately bad sulfur banding by selection of proper welding materials.

Ordinarily, there are but two main criticisms of manual submerged-melt welding. From the operator's viewpoint, the joint is hidden by the welding composition and he cannot see what he is doing. This objection is natural but can be minimized or overcome by proper techniques or by the use of guides which are easily attached to the welding hopper. This objection usually becomes of little concern as the operator's experience and confidence increase. A second objection concerns the cost and complexity of manual submerged melt-welding apparatus compared with the length of cable and the electrode holder required for manual, coated electrode welding. It should be remembered, however, that the submerged-melt welding apparatus is a semiautomatic machine which, where applicable, will produce more work at lower cost than an entirely hand-operated device. Its cost and maintenance expense are therefore normal items of shop cost which must simply be balanced against expected production savings as with any other machine.

APPARATUS DESCRIPTION

Manual submerged-melt welding apparatus consists basically of a portable drive unit and flexible wire conduit terminating in a holder or guide at the welding end as shown in Fig. 1. With this machine, which is the most common type, the wire feeding unit includes a wire feed control, drive motor and wire reel. The welding composition is held in a small container or hopper which is attached to the wire feed nozzle at the end of the flexible conduit. This nozzle and hopper assembly is held in the operator's hand and the granular material flows by gravity from the hopper end to the weld zone. The welding wire is driven through the nozzle which is insulated from the hopper, and the granular material surrounds it as it emerges from the tip. The hopper holds 3 to 5 lb of welding composition. In some apparatus, the flexible conduit with its nozzle and hopper assembly may be used separately from the portable drive unit by attaching it to a machine welding head. Such an arrangement provides for both fully mechanized and manually guided semiautomatic welding with minimum investment. Another type machine contains approximately the same components but in addition incorporates a large pressurized hopper, mounted with the wire feeding unit, which feeds the welding composition through a flexible tube to the weld zone. This hopper

Fig. 5 Welding stay bolts to side sheets in boiler fabrication

holds 75 lb of material and therefore requires only infrequent filling. The rated capacity for all those commercially available machines is in the neighborhood of 800 amp. Commonly used sizes of wire are $^3/_{32}$ and $^1/_8$ in. diam, with the $^3/_{32}$-in. size being most widely used. The flexible conduits can be obtained in 10- or 17-ft lengths.

OPERATION OF EQUIPMENT

No special skill or knowledge is essential to operate manually guided submerged-melt machines and proficiency is quickly developed once the operator feels at ease with the equipment. Very few preliminary steps are required prior to making the actual weld. Current and voltage required for the job are known either from previous shop experience or from data tables furnished by the machine manufacturer. The voltage settings are usually made by adjusting a knob on the control panel. It is good practice to keep the wire conduit assembly as straight as possible during welding to minimize motor loading. The tubes are flexible so as to be readily manipulated but no good purpose is served by unnecessarily laying it in coils or bending it sharply.

Before starting a weld, the operator should have the hopper filled with welding composition and should hold it in a horizontal position with the end of the wire over the starting point of the weld. The wire should protrude a minimum distance, approximately $^3/_4$ in., beyond the end of the hopper. When the hopper is turned vertically, the welding composition will cover the starting point and welding can be initiated by scratching the wire through it against the weldment. When the welding action is started, the hopper should be moved uniformly along the seam. The wire feed control will compensate for changes in height at which the hopper is held and will maintain the arc length constant. The major effect of increasing or decreasing the height at which the hopper is held is to regulate the depth of welding composition.

Most operators find it easier to weld long seams with the hopper handle pointing in the direction of welding rather that at right angles to it and this technique is recommended wherever the weldment position permits it. The flexible conduit is more rapidly manipulated when held in this position. However, it is not always possible to follow this technique because of position or restrictions close to the weld zone.

A commonly used technique in welding is the "drag" method in which the tip guard or riding-guiding attachment is in contact with the work and the hopper and nozzle assembly is literally dragged along. In using this technique, the weight of the hopper is removed from the operator's hand and a positive, natural guide is provided to center the wire on the seam. The operator can then concentrate on maintaining uniform travel speed.

In welding square groove joints with no root opening and joints with steel backing, the wire should be in a vertical plane through the seam and tilted slightly in the direction of welding. Flat position vee-groove joints are best made with a vertical electrode as shown in Fig. 2. The "drag" technique and use of a guiding attachment are also illustrated in this figure.

Fillet welds can also be made using the "drag" technique. The wire should be aimed directly at the seam, tilted 40 to 45 deg from the vertical member and 10 deg trailing as shown in Fig. 3. The same technique is recommended for making lap fillet welds except that the electrode should be inclined only 15 deg from the vertical surface.

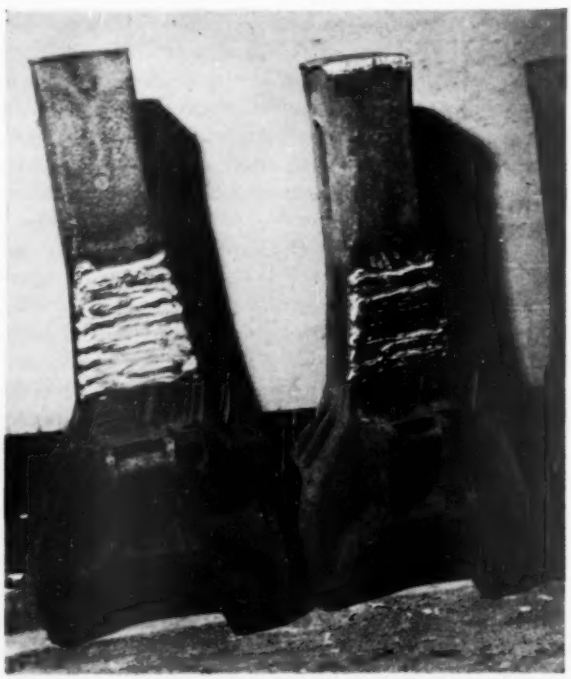
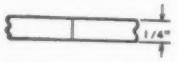
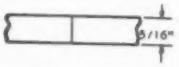
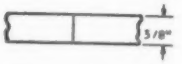
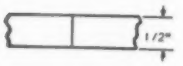
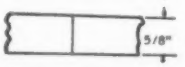
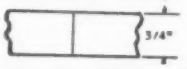


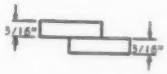
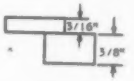
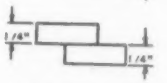
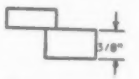
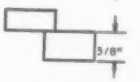
Fig. 6 Worn surfaces of railroad couplers are quickly rebuilt with the flexible welder

Table 1—Manual Submerged-Arc Welding Data for Square-Groove Welds

Joint	Pass	Current, amp	Arc voltage	Speed, ipm
	1	340	30	38
	2	460	33	38
	1	400	31	36
	2	500	33	34
	1	500	33	32
	2	540	33	28
	1	520	32	30
	2	550	32	24
	1	600	35	30
	2	660	35	35
	1	650	37	27
	2	675	37	29
	1	700	38	25
	2	700	39	27

NOTE: All wire $^3/_{32}$ in. diam.

Table 2—Manual Submerged-Arc Welding Data for Lap Welds

Joint	Current, amp	Arc voltage	Speed, ipm	Leg size, in.
	450	30	36	$^3/_{16}$
	500	30	40	$^3/_{16}$
	460	30	24	$^1/_4$
	480	30	19–20	$^5/_{16}$
	480	30	15	$^3/_8$

NOTE: All wire $^3/_{32}$ in. diam.

A "feel" for the handling of the apparatus can be developed by using the concentric hopper and the handle to orient the wire with respect to the work. If the handle is held parallel to the seam and pointing in the direction of travel, the wire automatically will be given a fixed trailing angle due to the angle between the hopper and handle. For welding with the wire in the vertical position, the operator can sight along the sides of the hopper and use it as a guide.

EFFECT OF VARIABLE ON WELD APPEARANCE

The effect of the common variables such as voltage, current and travel speed on the weld is the same for manual submerged melt welding as it is for welding with automatic machines. Welding current is the most important variable. Too little current results in lack of sufficient deposited metal while too much will burn through or produce excessive reinforcement.

The effect of high voltage is to flatten the weld and to produce undesirable secondary wash of the weld metal. This effect shows as "ears" at the upper edge of the weld when the weld cross section is etched. Low voltage causes peaking of the weld reinforcement and a weld cross section that is too deep for its width. With manual equipment, low arc voltage welding is more difficult than high voltage welding because the arc length is shorter and therefore there is a greater tendency for the operator to touch the wire to the work. Normal voltages for manual submerged melt welding are of the order of 30 to 35 v. Variations in travel speed have somewhat the same effect as a change in welding current. Too slow a speed causes excessive build-up and possible burn-through. Undercutting and peaking of the weld occur if the speed is too high. Probably travel speed is the major concern of the operator. While he can preset current and voltage for automatic control, he must maintain the travel speed himself all during the welding operation. Depth of deposit of the granular welding composition is also a variable under the operator's control, but the operator soon finds it an easy matter to maintain the correct amount. Holding the hopper too high deposits an excessive amount of welding composition which has a tendency to make the weld rough and uneven. Excessive amounts of composition also increase rehandling and shorten the welding time before the hopper must be refilled. Two shallow a layer of granular material results in arc flashing and atmospheric contamination.

WELDING DATA TABLES

Welding data for many standard joints have been obtained and tabulated to represent desirable operating conditions. When training new operators, lower welding currents and speeds are desirable until the operator attains proficiency with the apparatus.

Table 1 gives welding data for square groove butt welds. Currents up to 700 amp are recommended which permits two-pass welding of $^3/_4$-in. plate at speeds of approximately 27 ipm. Speeds up to 38 ipm can be used in welding $^3/_{16}$-in. thick sheet.

Lap fillet welds can also be made at high speeds as indicated by the data shown in Table 2. A $^3/_{16}$-in. lap fillet, for example, can be made at speeds of approximately 40 ipm.

The square groove welds with steel backing shown in Table 3 require greater metal deposit than do welds with tightly butted edges. Recommended currents are high enough to provide the required weld metal and still maintain high travel speeds. For example, a $^3/_{16}$-in. thick joint spaced $^1/_8$ in. apart can be made at speeds of 40 ipm using 600 amp.

Table 3—Manual Submerged-Arc Welding Data for Square-Groove Welds with Steel Backing

Joint	Current, amp	Arc voltage	Speed, ipm
10 GA – 3/32" GAP	500	30	40
3/16" – 1/8" GAP	600	30	40
3/8" – 5/32" GAP	750	35	20
3/8" – 3/16" GAP	750	35	16.5

NOTE: All wire $^3/_{32}$ in. diam.

Table 4 gives welding data for heavy plate fabrication using single- and double-vee groove preparations. Plates up to 1 in. thick can be welded in one pass from each side with speeds of approximately 13 ipm and currents of 700 amp. Steel plate $^3/_4$ in. thick can be welded from one side at 800 amp and 13 ipm. This is the maximum thickness of material which can be welded in one pass.

Table 5 shows data for flat and horizontal fillet welds. The maximum size horizontal fillet which can be produced in one pass is $^3/_8$ in. This fillet can be made at 15 ipm using 480 amp. Larger fillets can be made in the flat position. A $^1/_2$-in. fillet, for example, can be made at 600 amp and 10 ipm in one pass. Weaving can be used to make still larger fillets in the flat position.

The horizontal fillet welds are probably the most difficult welds to make. In addition to the variables already discussed, positioning of the wire is also an important consideration. Undercutting at the top toe of the fillet can occur either from excessively high voltage or from aiming the wire too far from the root toward the vertical leg. Aiming the wire improperly may also result in too much metal being deposited on one side of the joint. Excess current for the travel speed employed will result in a tendency for the weld metal to roll on the horizontal leg.

Table 4—Manual Submerged-Arc Welding Data for Single- and Double-Vee Groove Welds

Joint	Pass	Current, amp	Arc voltage	Speed, ipm
60° 1/4" 3/4" 60°	1	700	35	29
	2	700	35	29
60° 1/4" 1" 60°	1	700	37	13
	2	700	37	13
45° 3/4" 1/8"	1	800	38	13

Table 5—Manual Submerged-Arc Welding Data for Flat and Horizontal Fillet Welds

Joint	Pass	Current, amp	Arc voltage	Speed, ipm	Leg size, in.
3/16"	1	460	30	36	$^3/_{16}$
1/4"	1	460	30	24	$^1/_4$
5/8"	1	480	30	15	$^3/_8$
1/2"	1	500	31	18–20	$^5/_8$
	2	500	31	18–20	
	3	500	31	18–20	
3/4"	1	600	38	10	$^1/_2$
3/4"	1	620	37	12	$^{11}/_{16}$
	2*	620	32	15	

NOTE: All wire $^3/_{32}$ in. diam. * Weaving.

APPLICATIONS

Figure 4 shows manual submerged-melt welding applied to boiler fabrication. The irregular shape of this joint would make it difficult to set up for mecha-

Fig. 7 Accessories are added to railroad-car center sill by the flexible welder

Fig. 8 Manual submerged-melt welder is used to repair defects in a slag pot

nized welding. Stay bolts, $^3/_4$ in. in diam, are welded to $^5/_{16}$-in. thick side sheets in approximately 20 sec using 300 amp as shown in Fig. 5.

The railroad industry has many applications of manual submerged-melt welding in both maintenance and construction work. The couplers shown in Fig. 6 were worn on the shanks and butt ends and reclaimed by resurfacing with weld metal. Manual submerged-melt welding produced such a smooth deposit that it eliminated 75% of the finish grinding normally required when coated electrodes were used. Also, it reduced the time required to build up the shank sections from 45 to 5 min.

Figure 7 shows an operator attaching a part to the center sill of the railroad car by making a horizontal fillet weld. Many other parts are assembled in the same manner. The sill itself was fabricated by the machine in the background which joined together the two structural "Z" bars which make up the assembly.

Fig. 9 When damaged area is large, a plug is quickly welded in with the flexible welder

The slag pots shown in Fig. 8 are used in a steel mill to remove slag from open-hearth furnaces. When they become eroded, the damaged areas are flame-gouged and filled with weld metal. In some cases when the damaged areas are large, a plug is welded in place as shown in Fig. 9. Manual submerged-melt welding proved to be 7 to 8 times faster than coated electrode welding on this application. Between 9 and 15 lb of metal are deposited per hour or approximately 75 lb per 8-hr shift.

SUMMARY

Although manual submerged-melt welding is widely used at present, it has by no means reached its peak. Indeed, it is expected that its application will continue to expand as rapidly as it has done in the last several years because it offers the following advantages: (1) High deposition rate. (2) Semiautomatic operation with the flexibility of manual operation. (3) Weld quality equivalent to mechanized submerged-melt welds. (4) Elimination of visible arcing, spatter and greatly reduced fuming. (5) Flexibility in selection of power supply. (6) Application to a wide range of metals.

Arc Welding Embrittlement of Powder Metals

An investigation of embrittlement of powder metal due to the effect of porosity and the role of copper in iron-copper composition

by Albert Sill, Jr., and C. C. Mathias

Abstract

Excessive grain growth was encountered in normal arc welding of electrolytic powdered iron bushings (average density 6.0 g/cc) to a low-carbon plate. Arc welding of iron-copper powder metal bushings (average density 6.0 g/cc) to a low-carbon plate introduced a brittle iron-copper grain boundary constituent.

Low ductility was evident in the electrolytic iron welded bushings and the iron-copper bushings were quite brittle after welding.

Higher density powder iron bushings (average density 7.6 g/cc) showed almost complete absence of grain growth after welding and ductility approached that of the welded 1020 bushings.

High-density 4650 powder metal (7.5 g/cc) bushings, welded without preheat or postheat, showed some grain growth, but fractured with considerably more toughness than the low-density electrolytic iron or the iron-copper bushings.

INTRODUCTION

IN ATTEMPTING to weld several sintered powder metal bushings to farm machinery it was found that the sintered metal became quite brittle adjacent to the weld. Two possible answers were investigated, namely:

1. The effect of porosity.
2. The additional role of copper in the case of iron-copper compositions.

Seitz[1] has postulated that the creation of surface requires work and that the process must be accompanied by a force. Conversely it follows that internal porosity may be a source of energy to start structural changes to a form of lower free energy per unit of area. Seitz further postulated that since surface atoms have higher free energy than internal atoms, it follows that any aggregate of crystals tends to unite in order to decrease the amount of surface. With a wealth of energy of activation available in the electric arc and the molten weld metal, it was decided to make a metallographic study of the weld areas.

Further consideration had to be given to the work of Mehl and Anderson[2] in their studies of nucleation (N) and growth (G) phenomena. They have shown that nucleation increases with increasing amounts of cold work.

In pressing the powder, the grains of material are subjected to varying degrees of plastic flow and, therefore, should favor nucleation of many small grains in preference to a few large grains.

In the case of iron-copper compositions the effect of

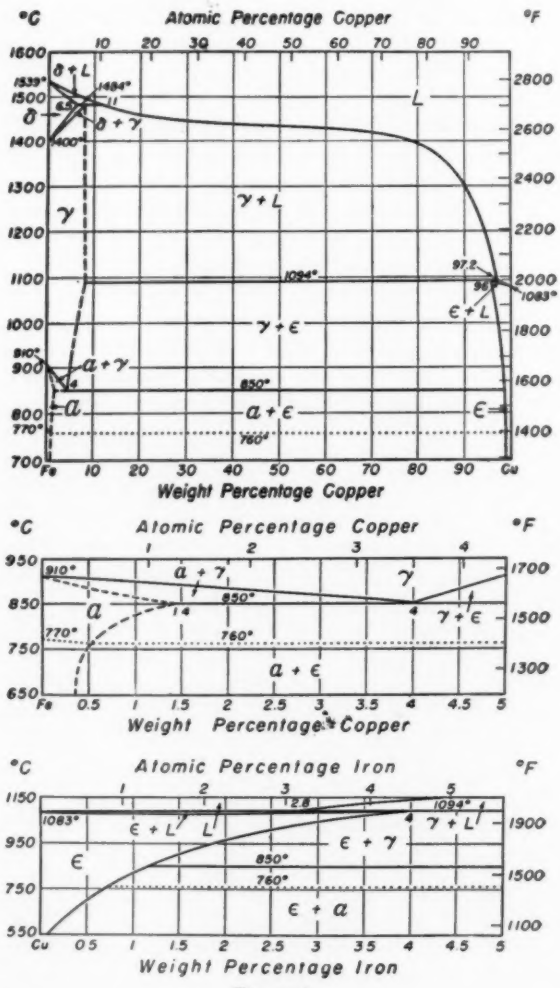


Figure 1

Albert Sill, Jr., is Welding Engineer and **C. C. Mathias** is Metallurgist, New Holland Machine Division, Sperry Corp., New Holland, Pa.

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welding temperatures on the iron-copper phase relations was indicated. The iron-copper diagram[3] shown in Fig. 1, contains a peritectic at approximately 2000° F and the question of the eta (η) phase relation to ductility arose.

PURPOSE

(*A*) Testing Material

Quantity	*Size*	*Description*
2	3/16 x 7 x 18 in.	SAE 1020 C.Q. steel plate
2	0.500 to 0.510 in. ID x 0.875 in. OD x 0.5 in. long	Electrolytic iron D, 7.6 g/cc
2		4650 alloy powdered metal D, 7.5 g/cc
4,		SAE 1020 C.Q. steel bushing
4,		ASTM B222-52 sintered powdered metal D, 6.0 g/cc
4/		Electrolytic iron D, 6.0 g/cc

(*B*) Testing machine and electrode transformer type—ac, dc—300-amp AWSE 6013, 1/8 in. ϕ—130-amp straight polarity

(*C*) Testing Procedure

1. Prewelding inspection of ID and OD for uniformity.
2. Steel plate positioned and clamped to standard welding table.
3. Two specimens positioned and tack welded. (SAE 1020 C. Q. steel welded first to determine correct amperage settings.)
4. Specimens completely welded on OD.
5. Items 3 and 4 repeated for remainder of specimens.
6. Welded "assembly" allowed to cool to room temperature.
7. Removal of spatter from ID inspection of ID for change in dimension and roundness.
8. Destructive testing of two specimens from each group "assembly" held in bench-vice during testing.

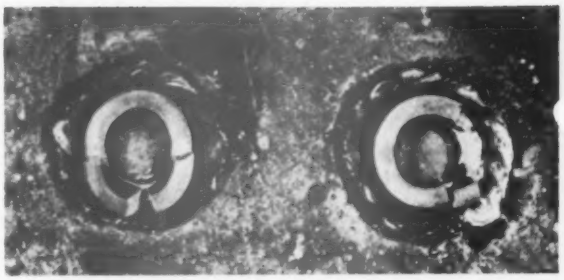

Fig. 2 Welded electrolytic iron

(*a*) SAE 1020 steel specimen 1/2 ϕ x 8 in. long C.Q. steel bar inserted in ID and struck on outer end with 2 lb hammer.

(*b*) ASTM B222-52 sintered powdered metal density 6.0 g/cc.
Electrolytic iron density 6.0 g/cc.
Electrolytic iron density 7.6 g/cc.
4650 alloy powdered metal density 7.5 g/cc.
Above specimens tested same as (*a*).

(*c*) ASTM B222-52 sintered powdered metal density 6.0 g/cc.

9. Remainder of specimens cut and etched.

After welding, the electrolytic iron bushings of low density were structurally weak as shown by Fig. 2. Rupture appeared to start at toe of the weld. Macroetching showed no apparent cause for the weakness in the area adjoining the weld.

Photomicrographs at 100 × (Fig. 3) and at 500 × (Fig. 4) showed excessive grain growth in the bushings adjoining the weld metal. It will be noted that a few spherical voids still remain in the recrystallized area.

High-density sponge iron bushings (density 7.6 g/cc) as welded were quite ductile and withstood hammer blows (2 lb hammer) on the end of a 8 in. long by 1/2-in. diam bar with no distortion or sign of brittleness (Fig. 5). Macroetch tests of the welds were quite

Data Sheet

Specimen	*Prewelding inspection, ID*	*Postwelding inspection, ID*	*Welding time, min. avg*	*Comments*
SAE 1020	0.5095 0.5095 0.5095 0.5095	0.5090 0.5090 0.5087–0.5092 0.5090	0.43	Slight under cut. Good weld surface. Average or normal penetration. No porosity or cracks. Bushings ductile on impact.
ASTM B222-52 sintered powder metal, density 6.0 g/cc	0.5100 0.5100 0.5100 0.5100	0.5085–0.5110 0.5060–0.5100 0.5105 0.5090–0.5115	0.495	Good weld surface. No under cut. Deep penetration. No porosity or cracks. Bushings quite brittle on impact.
Electrolytic iron, density 6.0 g/cc	0.5110 0.5110 0.5110 0.5110	0.5110–0.5120 0.5115 0.5118–0.5098	0.46	Good weld surface. No under cut. Deep penetration. No porosity or cracks. Bushings lacked ductility under stress.
Electrolytic iron, density 7.6 g/cc	0.4963 0.4963	0.4932–0.4981– 0.4960	0.43	Good weld surface. No under cut. No porosity or cracks. Average or normal penetration. Bushings ductile on impact.
4650 alloy powder metal, density 7.5/g/cc	0.4975 0.4975	0.4950–0.4965– 0.4970	0.425	Good weld surface. No porosity or cracks. No under cut. Average or normal penetration. Fractured, but tougher on impact than iron-copper.

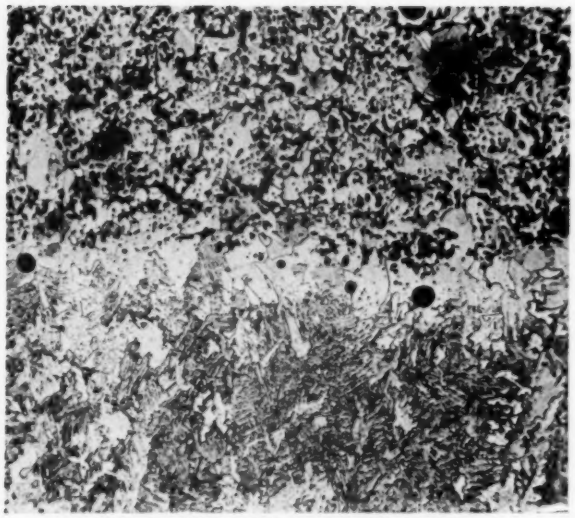

Fig. 3 Electrolytic iron weld. ×100.

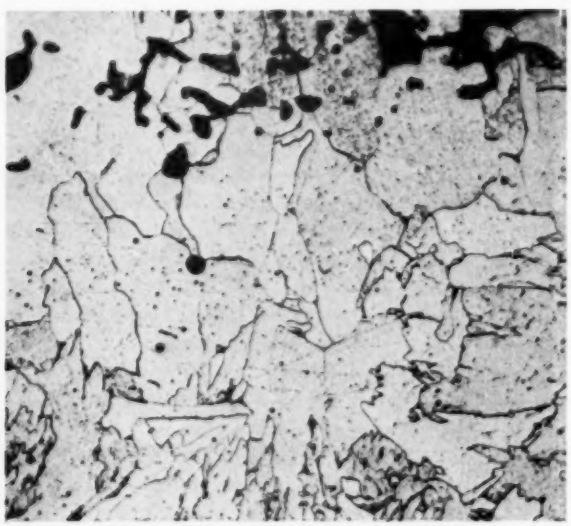

Fig. 4 Electrolytic iron weld. ×500

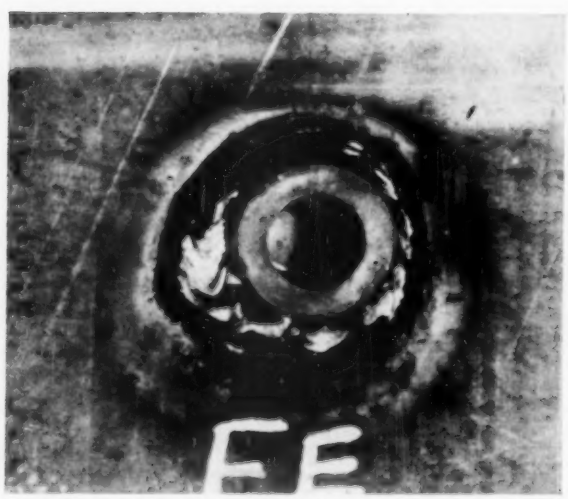

Figure 5

similar to those made on bushings machined from 1020 bar stock.

Photomicrographs at 100 × (Fig. 6) and 500 × (Fig. 7) showed almost complete absence of excessive grain growth.

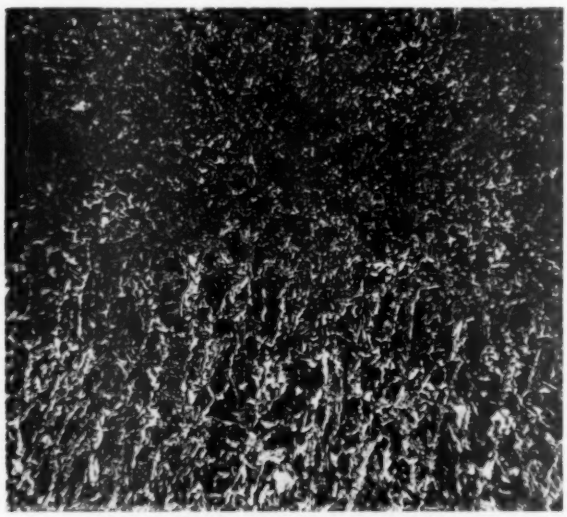

Fig. 6 High-density iron weld. ×100

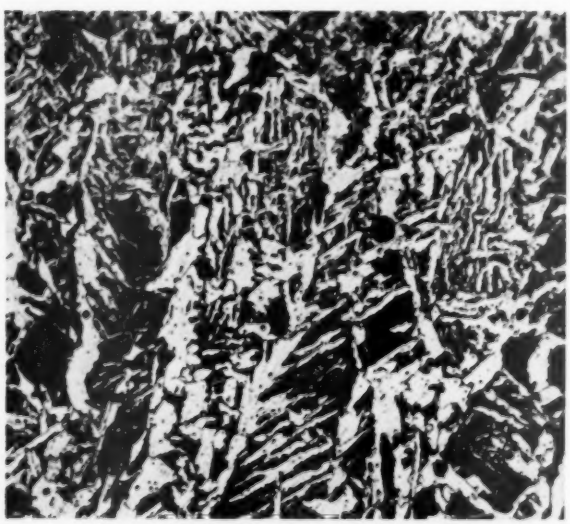

Fig. 7 High-density iron weld. ×500

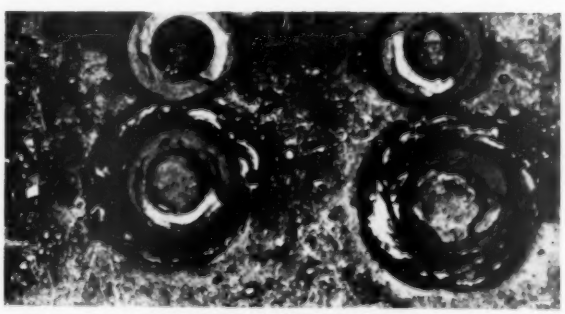

Fig. 8 Welded Fe-Cu

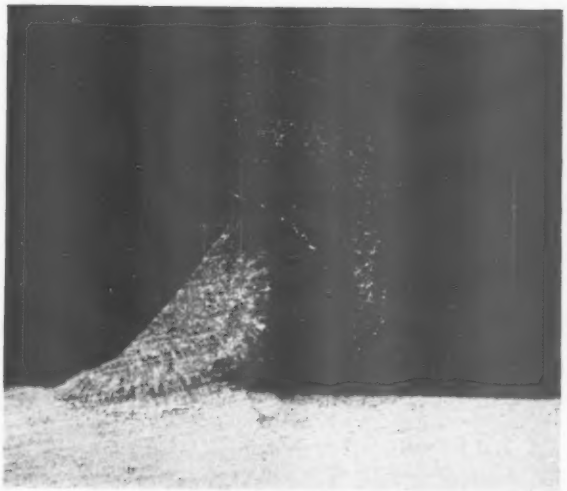

Fig. 9 Macroetch Fe-Cu

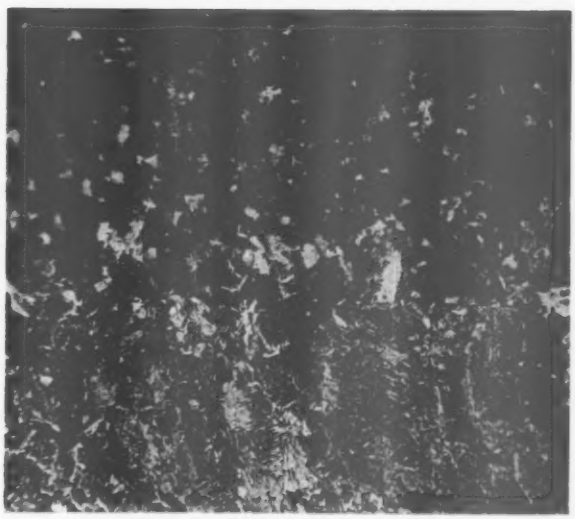

Fig. 10 Welded Fe-Cu. ×100

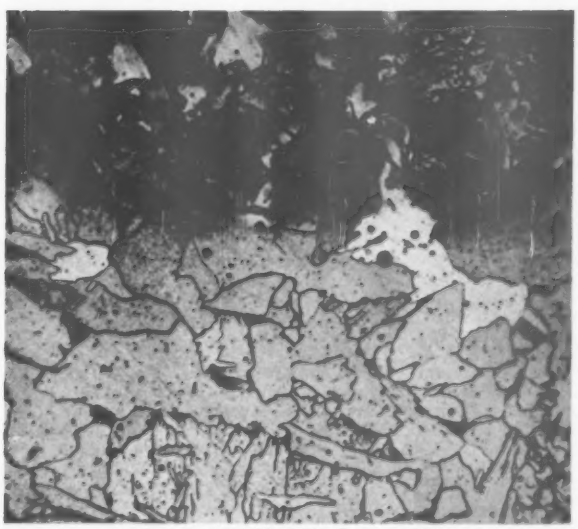

Fig. 11 Welded Fe-Cu. ×500

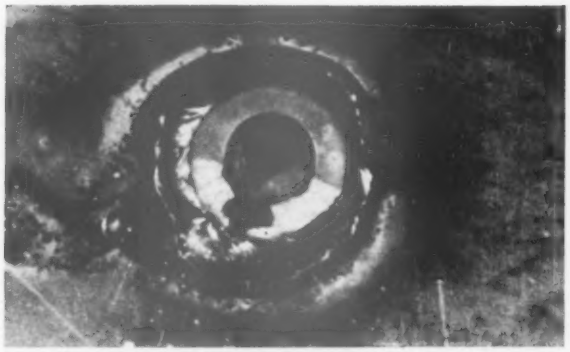

Fig. 12 Welded 4650 bushing

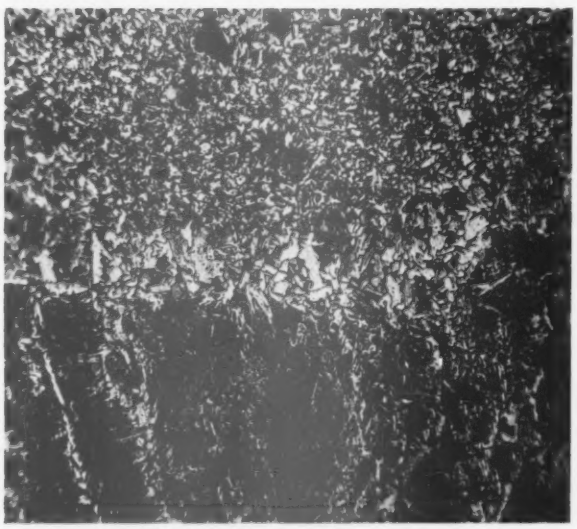

Fig. 13 Welded 4650. ×100

Low density iron-copper (6 to 10% Cu) bushings as-welded were quite brittle and broke off above the weld with a glasslike snap (Fig. 8).

Macroetching of the weld area showed a well-delineated band of a distinctly different phase than the basic sintered iron-copper composition (Fig. 9).

Photomicrographs at 100 × (Fig. 10) showed only the presence of difference in the grain size, but at 500 × (Fig. 11) the presence of the new phase is quite evident.

A bushing of sintered alloy powder (4650) was included in the welding test. With no preheating or postheating, this bushing fractured diagonally with considerable impact and appeared to be rather tougher than brittle (Fig. 12). Macroetching showed no indications of abnormal structures.

Photomicrographs at 100 × (Fig. 13) showed indications of grain growth. Photomicrographs at 500 × (Fig. 14) showed the area of growth to have a mixed fine and coarse grain structure. A few martensitic areas are also indicated.

Fig. 14 Welded 4650. ×500

DISCUSSION AND SUMMARY

Structural weakness of the welded low-density electrolytic iron bushings can be contributed to excessive grain growth in the area adjoining the weld. Several factors are felt to contribute to the excessive growth, namely:

1. Increased surface area of the voids with attendant higher free energy available to activate the growth mechanism.
2. Presence of unstressed surfaces in the voids to act as centers of nucleation.

Brittleness of the welded low density iron-copper bushings can be contributed to the same porosity influences as the electrolytic iron plus the peritectic reaction which produces excessive eta (η) phase (copper-rich) material in the grain boundaries.

The almost complete absence of grain growth in the welded high-density iron bushings can be contributed to increased nucleation with increased cold work and the absence of excess voids for early random nucleation.

Welded 4650 high-density bushings were subject to grain growth of a mixed nature. Some grains grew in preference to others and this is probably due to the greater resistance of alloy powders to flow and compact. In other words cold working of the particles in the powder press was of a random nature, resulting in high and low nucleation rates in adjacent or neighboring powder particles. The welded 4650 powder metal bushings were considerably tougher than the low-density iron and further work employing preheating and postheating is being considered to further increase the toughness by reducing the random martensitic areas found in the areas adjacent to the welds.

We have not been able to obtain high-density material in the iron-copper compositions except on a laboratory scale and no further work is contemplated with this material.

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(*Continued on page 867*)

Iron Powder Electrodes and Their Application

Advantages of the rutile plus iron powder type electrodes properties and recommended techniques to get the best results

by Jerry Hinkel

INTRODUCTION

AMERICAN-made electrodes with large quantities of iron powder in their coatings were introduced in this country less than a year ago. The reception they have received indicates that they are here to stay. Their introduction will eventually be considered one of the more important milestones in the progress of arc welding.

The idea of adding iron powder to a coating is not new. It has intrigued electrode designers almost from the very first days of coated electrodes, and actually, some electrodes with iron powder in their coatings have been available from overseas sources for several years. However, none of these electrodes has ever enjoyed any great popularity in this country, partially because they did not offer the desired operating characteristics and partially because they were extremely high priced.

American development of iron powder electrodes has overcome these difficulties and indicates that any of the common electrode coating types will lend themselves with some modification to the addition of iron powder. At the present time, there are a few iron powder electrodes available which could be described as organic, or all position, and there are also a few which could be described as iron oxide or mineral type. But by far the most popular of the iron powder electrodes available at this time are those which we could best describe by saying that they are of the rutile type.

While it is perhaps a grave injustice to the electrode designer to supersimplify his design problems by calling these electrodes rutile plus iron powder, we will take the liberty of doing this as it will help us to better understand the general nature of the product involved. This name, "rutile iron powder," seems to be most appropriate because these products certainly do have more in common with conventional rutile E-6012 and E-6013 types than any of the other standard types.

This report will discuss the rutile plus iron powder type electrodes. Discussion will be confined to this type since the other two types, all position and iron oxide, are hardly past the field test stage, and very little reliable information is available on them.

Now that industry in general has accepted iron powder electrodes so eagerly, it seems strange that this development did not come along sooner. From the standpoint of the electrode manufacturer, it was not so much a case of a long development project, but rather a matter of trying to decide whether the welding industry would accept a product so completely new and different. Also it was important and problematic as to how much a premium price the final product would have to carry. Experience had indicated that the foreign types had been too high priced to gain acceptance. It was also very important to know what new manufacturing problems the new product would present.

In less than a year, all of these questions have been satisfactorily answered. Welding operators are well pleased with the product, and the electrodes have not presented very many serious manufacturing problems. Also the final selling price is considerably lower than was originally anticipated.

Electrode designers have favored the use of iron powder since it almost automatically produces higher deposition rates, better weld appearance and very smooth, steady arc characteristics.

HIGHER DEPOSITION RATE

Probably the most important single advantage of iron powder electrodes is their very high deposition rate. Figure 1 compares the deposition rate in pounds per minute of an iron powder electrode and one of the fastest E-6012 electrodes available today.

In the case of each wire size, the best practical current is indicated. By confining attention to this practical current, or optimum current, the facts will not be distorted by results which are likely to occur only at a higher current than would be consistent with good all-around performance. The illustration clearly shows that higher current values are in order for iron powder electrodes. It also indicates that even if a smaller iron powder electrode is used—and this frequently is the case—it will still deposit weld metal at a faster rate of speed. A $^{5}/_{32}$-in. iron powder electrode has a higher deposition rate at 250 amp than does a $^{7}/_{32}$-in.

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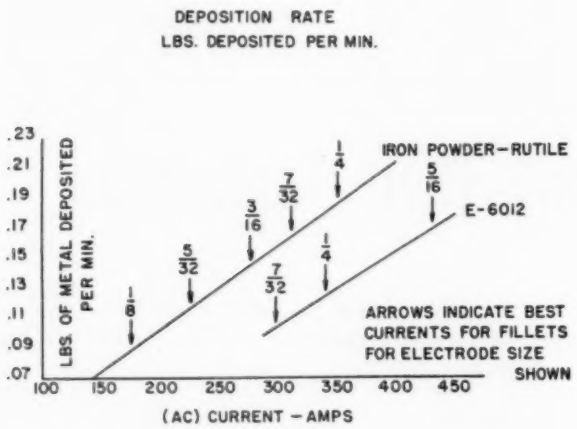


Fig. 1 Iron powder electrodes are capable of depositing weld metal approximately 50% faster than conventional electrodes

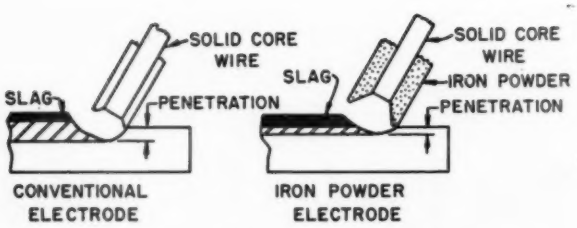


Fig. 2 The heavy coating of iron powder electrodes produces a crucible effect up in the electrode so that the electrical energy of the arc is more efficiently used in melting the electrode and coating

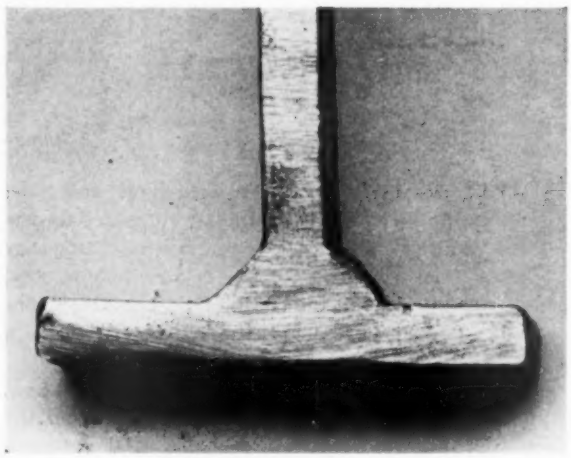


Fig. 3 The bead shape of a conventional fillet (right) compared to that of an iron powder electrode (left). With iron powder no metal is wasted in excessive convexity

E-6012 electrode at 300 amp. Size for size iron powder electrodes are capable of depositing weld metal approximately 50% faster than any conventional electrode.

This, then, represents the potential speed advantage. The explanation why this higher deposition rate exists is found in the analogy described in Fig. 2.

It has been said that the metal arc process actually makes steel by the electric furnace method. An electrode serves as a source of electrical energy and as a source of filler metal. There is also a crucible in which to melt the steel. The analogy holds for either type of electrode, E-6012 or iron powder.

However, there are some very interesting points of difference. For example, in the case of the conventional electrode the crucible effect occurs almost entirely in the base metal, while in the case of the iron powder electrode, it is more nearly correct to say that the crucible effect occurs, for the most part, up in the electrode itself. The conventional electrode, therefore, utilizes a far greater percentage of its electrical energy in melting the plate. The iron powder electrode confines most of its electrical energy up in the coating, and thus more efficiently utilizes it to melt the electrode. The coating itself contributes to this effect because of its relative thickness compared to conventional coatings.

Another interesting point of difference is that with the conventional electrode, all of the metal available to make the weld occurs in the form of a solid dense core wire. The iron powder electrode, on the other hand, has not only a core wire but an appreciable percentage of iron powder in the coating. Since this extra quantity of iron is the powder form, it naturally melts more readily.

Still another point of difference is that with an iron powder electrode a higher arc voltage occurs naturally. Thus, if the welding current is constant, the total electrical power (volts × amp) at the arc is considerably greater in the case of the iron powder electrode. Because of these arc characteristics, iron powder electrodes do not offer deep penetration. In some instances this is an advantage, as in the case of poor fit-up. In other instances it may be a disadvantage.

Deposition rate information, although interesting and very helpful in understanding a product's potential, is not the final answer. The only real important question, assuming the product will make a satisfactory weld, is whether or not it is actually faster and more economical to use on a given job.

Now in the design of these iron powder electrodes, the greatest emphasis was placed on getting good performance, especially on fillets and lap welds. This design purpose is predicated to a great extent on the fact that fillet welds represent by far the largest percentage of all the welding normally done.

In the final test of welding speed, other performance factors could nullify the speed advantage indicated by a deposition rate figure. Such things as excessively convex beads, excessive spatter or difficult handling characteristics all play a very large part in determining final arc speed. However, in the case of iron powder electrodes, all of these factors are conducive rather than deterrent to getting maximum arc speed. For example, in the case of fillet welds, the type of joint for which these electrodes are best suited, the bead shape is slightly concave to flat so that the result is an extremely economical fillet—that is, no metal is wasted in the form of excessive convexity. Also the

HORIZONTAL FILLET WELD

	PLATE SIZE	FILLET SIZE	ELECTRODE SIZE	CURRENT	ARC SPEED "/ MIN.
IRON POWDER	3/8"	1/4"	3/16"	270 AC	15.0
E-6020	3/8"	1/4"	1/4"	350 AC	12.0
IRON POWDER	3/8"	5/16"	1/4"	360 AC	14.0
E-6012	3/8"	5/16"	5/16"	400 AC	10.0

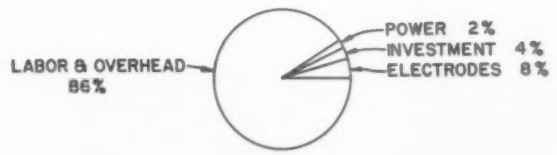


Fig. 4. A comparison between iron powder and E-6020 and E-6012 electrodes shows the higher speeds made possible through higher deposition rate. Large possible savings in labor and overhead cut into the major portion (86%) of welding cost

spatter loss is nil at almost any conceivable current, and the bead is smoother than any other manual method of welding.

Recommended procedures for fillet and lap welds are given in Fig. 4 and show the greater arc speeds which can be obtained with iron powder electrodes. Figures 5, 6 and 7 show the appearance standards which were maintained in developing these procedures. Any size conventional fillet can be made at a correspondingly higher arc speed using iron powder electrodes. This higher arc speed amounts to a very real saving to the user since it has a direct bearing on the labor and overhead portion of costs which represents approximately 86% of the total welding cost.

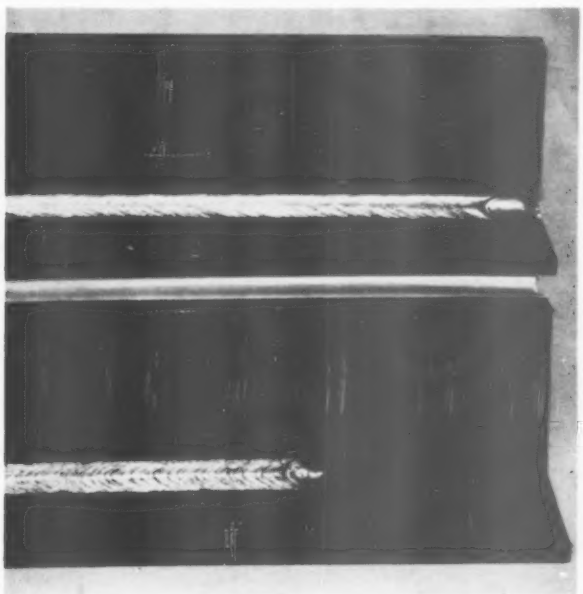


Fig. 5 High speeds are attained with a high standard of appearance. The top weld was made with a single iron powder electrode, and the bottom with a single E-6012 electrode. The iron powder electrode was 36% faster, with better appearance

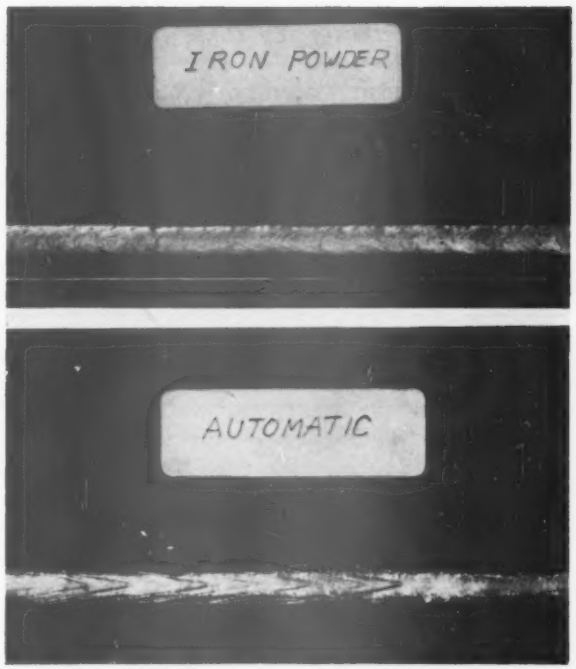


Fig. 6 Welds made with iron powder electrodes are comparable in appearance to welds made with automatic submerged arc process

RECOMMENDED CURRENT

The recommended current for electrodes of this type is generally somewhat higher than for conventional electrodes. (See Fig. 8.) An experienced operator can usually decide quickly without the benefit of an ammeter when he has a suitable current. However, because of the very smooth, steady arc characteristics of these electrodes, an operator could select a welding current which was too high to obtain the best welding quality. This is quite possible since these electrodes exhibit none of the usual warning signals. The coating does not break down, the arc does not become extremely harsh and very little spatter occurs even at very high current.

Fig. 7 Deep groove welds have excellent appearance and wash-in

RECOMMENDED CURRENTS				
ELECTRODE SIZE	CURRENT	POLARITY	FILLET SIZE	ARC SPEED "/ MIN.
5/32	225	AC	7/32"	15
5/32	200	DC +	7/32"	12.5
3/16	275	AC	1/4"	15
3/16	250	DC +	1/4"	12.5
1/4	350	AC	5/16"	14
1/4	300	DC +	5/16"	12

Fig. 8 Table of recommended currents

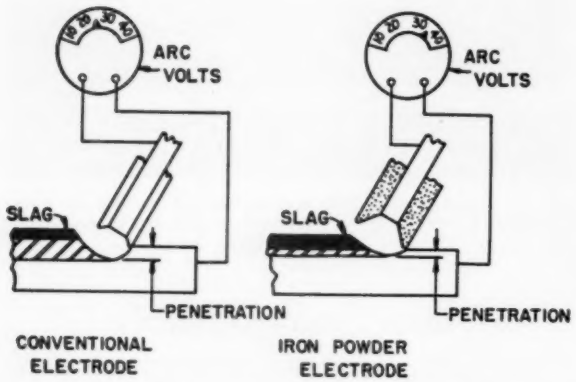


Fig. 9 The longer arc length of iron powder electrodes means higher arc voltage. Machine settings not calibrated for this voltage sometimes must be at a higher current value than would be expected to get recommended currents

Welding operators may have some difficulty in obtaining recommended currents by machine dial setting alone. This is possible because of the higher arc voltage nature of these electrodes. Since the dial calibrations on present-day machines were not made with this higher arc voltage nature in mind, it is generally necessary to set the current at a higher value than would be expected in order to get the recommended current. (See Fig. 9.)

Resistance to Arc Blow

While iron powder electrodes are recommended for both a-c and d-c operation, a c is preferred. For d-c welding, they have the unique distinction of resisting arc blow better than any other type of electrode. This is not to imply that arc blow will never occur, but in any case, the blow condition will be less severe and will be less prevalent than with any other electrode under similar conditions.

Since it is the nature of the slag to follow the arc closely, a preferential grounding condition which permits the operator to weld toward the ground rather than away from it, generally produces the best results.

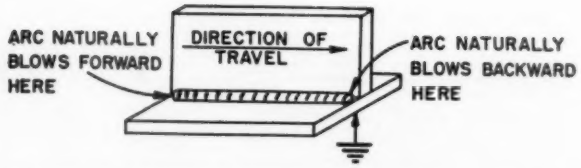


Fig. 10 Arc blow conditions are less severe with iron powder electrodes

Due to the close following slag, backward blow is no problem, but forward blow may sometimes be bothersome. Always welding toward the ground will practically nullify the blow condition.

Fig. 11 Spatter on weld made with E-6012 electrode (left) resulted from blow conditions when welding away from ground toward a completely open end. Under same conditions iron powder electrode (right) makes satisfactory welds

(See Fig. 10.) Figure 11 illustrates how arc blow is controlled on a butt weld.

CONTACT ELECTRODE

The heavy coating of iron powder electrodes makes them ideal for use with a contact or drag technique, and generally speaking, this produces the best and the fastest results. For those operators who prefer to hold an arc, there is no good reason for not doing so except that it is a more fatiguing method of welding.

AWS-ASTM ELECTRODE DESIGNATION NUMBER

The present AWS electrode specifications do not cover iron powder electrodes, and any attempt to qualify these products under these specifications requires some modification of the test procedure or some compromise in the interpretation of the specification. At the present time most of these electrodes are qualified by the American Bureau of Shipping and the United States Coast Guard as E-6012 Modified. This is to imply that they meet all of the requirements of the E-6012 type but for downhand welding only.

Some of these same electrodes could also be qualified as E-7020. In the latter case, all physical property

tests are conducted on stress-relieved samples, and all of the usability characteristics are consistent with the XX20 requirements. It is expected that the AWS-ASTM Filler Metal Committee will soon have a new specification to adequately cover electrodes of this type. When this is done these electrodes will carry an entirely different specification number.

WELDABILITY OF IRON POWDER ELECTRODES

Past experience has generally indicated that welds almost had to be convex in nature in order to resist cracking tendencies. Iron powder electrodes produce anything but a convex bead shape and are strangely enough very good for welding crack-sensitive steels. This is a little difficult to explain except from the standpoint of: (1) less admixture, (2) less total heat input and (3) higher strength weld metal. These factors, of course, affect shrinkage and the actual weld metal chemistry. In many instances E-6012 and even some low-hydrogen electrodes have been successfully replaced on crack sensitive applications with iron powder electrodes. (See Fig. 12.) Steels which are slightly high in either carbon, silicon or sulfur which would be likely to show a surface hole tendency when welding with either E-6013 or E-6020 electrodes can be satisfactorily welded using iron powder electrodes without any indication of surface holes. This advantage, however, does not carry over into the very high sulfur free-machining steels. This field seems to be reserved for low-hydrogen electrodes alone.

PHYSICAL PROPERTIES

In keeping with their rutile nature these electrodes have high tensile strength and relatively low ductility. Some changes have been made in physical properties and weld metal chemistry since they were originally introduced, and at the present time their properties are as follows:

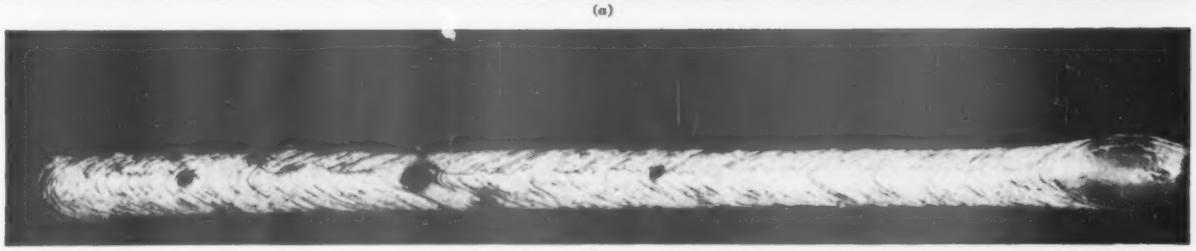
As-welded:

Yield, psi	65,000–75,000
Tensile strength, psi	80,000–90,000
Elongation in 2 in., %	18–25

Stress relieved:

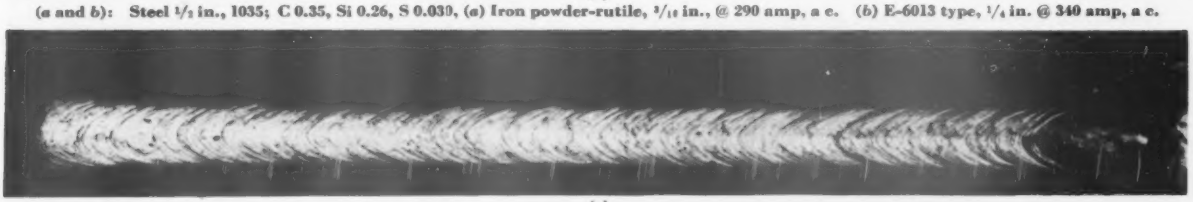
Yield, psi	65,000–75,000
Tensile strength, psi	80,000–90,000
Elongation in 2 in., %	25–30

(a)

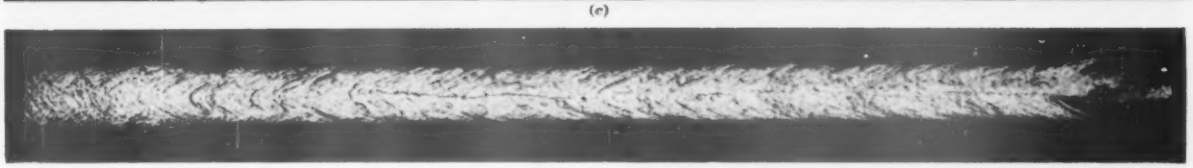


(b)

(a and b): Steel 1/2 in., 1035; C 0.35, Si 0.26, S 0.030, (a) Iron powder-rutile, 3/16 in., @ 290 amp, a c. (b) E-6013 type, 1/4 in. @ 340 amp, a c.



(c)



(d)

(c and d): Steel 1/2-in., 1035; C 0.35, Si 0.26, S 0.030, P 0.010, Mn 0.85. (c) Iron powder-rutile, 3/16 in., @ 290 amp, a c. (d) E-6020 type, 1/4-in., @ 350 amp, a c.

Fig. 12 Steels whose analysis is in the range indicated above exhibit a tendency for cracking and pinholing, particularly when welded with E-6020 and E-6013 electrodes. With iron powder rutile type electrodes this tendency disappears. All welds are horizontal fillets

Fig. 13 Excellent ductility is demonstrated by the smooth iron powder weld compared to the conventional E-6012 weld which cracked when this plate was bent. Surface condition affects ductility

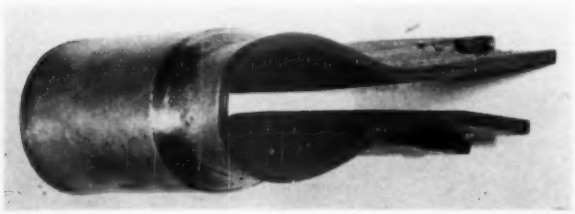


Fig. 14 A severe test for ductility did not crack this weld

Impact resistance (Charpy-keyhole notch):

Room temperature, ft-lb	28
−70° F, ft-lb	20
Transition temperature approximately	−100° F

As indicated above, stress relieving has a marked effect on elongation but practically no effect on tensile or yield strength. It is significant that aging even at room temperature for a sufficiently long period of time will accomplish practically the same results as stress relieving.

These properties represent a slight increase in tensile strength and elongation over E-6012 electrodes and a considerable improvement in impact resistance. At room temperature there is no appreciable difference. There is a marked difference at lower temperatures. Using 15 ft-lb as the minimum acceptable value, E-6012 electrodes reach their transition point at about −20° F. (See Fig. 15.) Iron powder electrodes reach their transition temperature in the neighborhood of −100° F.

This improvement in impact properties is very encouraging in view of the information which has been gained as a result of recent investigations into ship and tank failures, especially those which have been described as brittle failures. In practically all of these cases subsequent tests of the welds and the base metal indicated ample ductility based on conventional tension tests at room temperature, but more significant

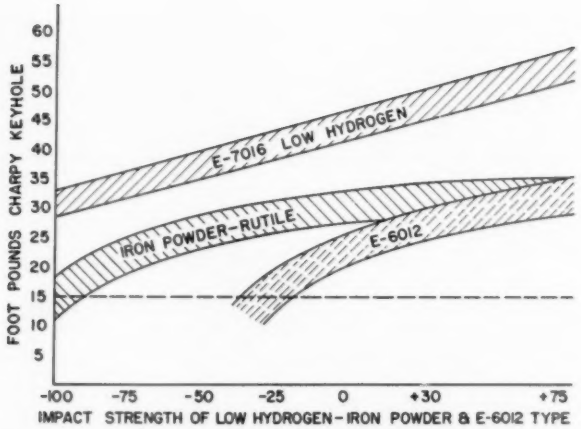


Fig. 15 Impact strength comparison showing transition points of various electrode types

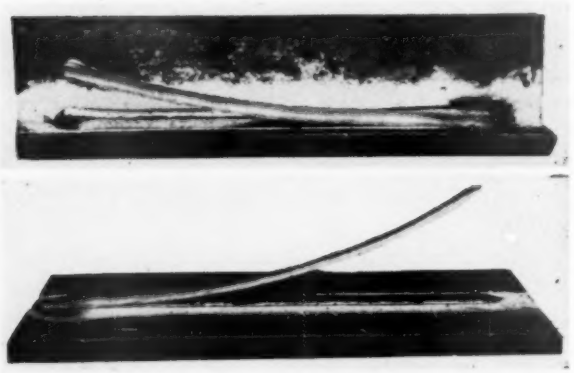


Fig. 16 Under favorable conditions slag is self-cleaning

Fig. 17 Wear-plates made of "Jalloy No. 3" are welded to the bottom of a dump truck body made of "Tri-Ten" steel

A continuous $^5/_{16}$-fillet joins the $^3/_4$- x 4 x 14-in. wear-plates to the body. Previous welding with a $^5/_{16}$-in. low-hydrogen electrode required 13$^1/_2$ hr welding time and 8 hr of cleaning and grinding. Now welded with $^1/_4$-in. iron powder electrode in 8 hr and 2$^1/_2$ hr cleaning—saving 10 hr per body.

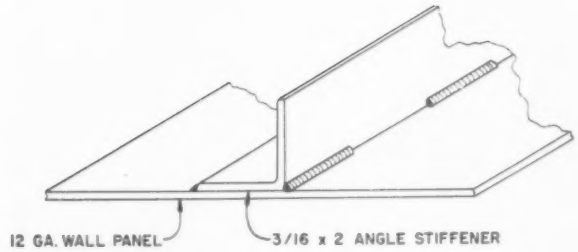


Fig. 18 The angle stiffeners on a wall panel for a metal hut were welded with an E-6012 electrode. Use of iron powder electrodes cuts the arc time on each panel by 50%

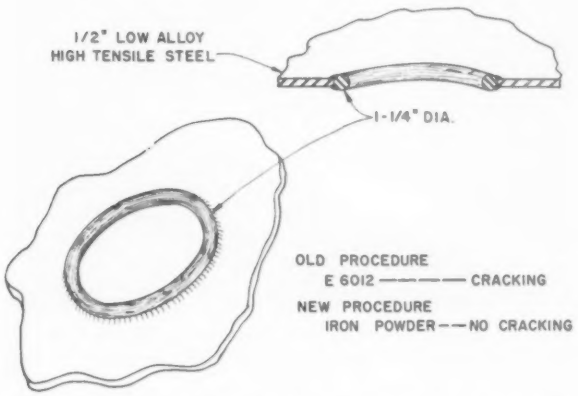


Fig. 19 The draw bar of a large earth mover has a hole through which control cables pass

A piece of 1¼-in. mild steel round stock is welded around the inside diameter of the hole to protect the cables. Because of stress concentrations in the joint set up by welding, cracking was a problem when using an E-6012 electrode. Iron powder electrodes, now used, have eliminated cracking

was the fact that the plate involved generally had relatively low impact resistance. In many cases they had a surprisingly high transition temperature. Most of these failures were coincident with low temperature.

This information would seem to indicate the need for maintaining adequate impact strength at low temperature. Iron powder electrodes have this ability as indicated by their low transition temperature. In this respect they are better than all other types except low hydrogen electrodes.

We should not overlook the significance of any inherent irregularities in the weld bead itself in the practical consideration of this same problem. Certainly any undercut, distinct ripples in the bead surface or a bead shape which offers severe stress concentrations could very easily contradict or nullify the impact nature as indicated by a carefully prepared all-weld metal impact specimen. On all of these points, iron powder electrodes have a distinct advantage over most other types; undercut is nil, the surface is very smooth and the bead shape is ideal from the standpoint of stress concentrations.

WIRE SIZE

Because of the additional metal in the coating and the unusually large coating diameter, it is generally

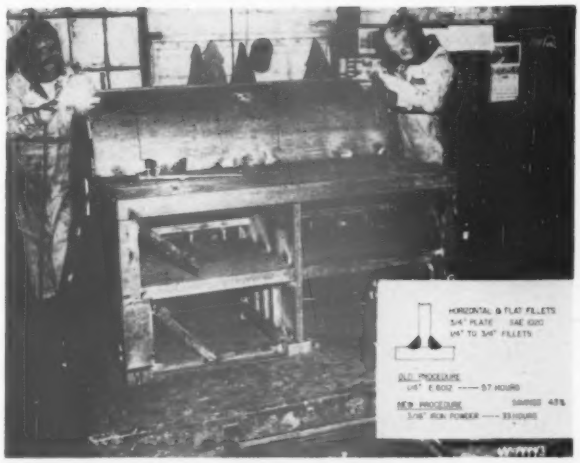


Fig. 20 The welding on this 900-lb weldment for a broach required 57 hr with E-6012 but only 33 hr with an iron powder electrode

possible to use one size smaller iron powder electrode to do the same job normally done with a conventional electrode. For example, in using a ¼-in. conventional electrode, the size fillet which comes easily and readily is ¼ in., but to get this same size fillet with iron powder electrodes, we would need use only ⁸/₁₆-in. or if we wish ⁷/₃₂-in. electrode. In some cases because of the existing plate preparations, the physical diameter of iron powder electrode coatings might make it mandatory to reduce wire size, but even with the reduction of wire size, we can invariably increase the welding speed.

SLAG REMOVAL

Figure 16 indicates the self-removing slag feature which can be obtained on most welds. This condition will occur providing a sufficient quench effect is present as in the case of the heavy plate, and providing the surface is smooth and free of undercut.

In a very tight V-joint it is not likely that the slag will remove itself. But since it is a fairly dense, solid slag, it can generally be removed without too much effort, and it will then usually remove very cleanly and completely.

In many applications the saving in time required to remove slag and spatter will amount to as much as is saved through increased welding speeds.

CONCLUSION

Iron powder electrodes are an evolutionary development in electric arc welding. They are not a completely new departure in electrodes nor do they make any fundamental change in the welding process. Because of this, in describing these electrodes, the same terms are used as are used for conventional electrodes, only we add "bigger and better." Unfortunately. our ears have become somewhat dulled by the too frequent use of these words, and the temptation might exist to dis-

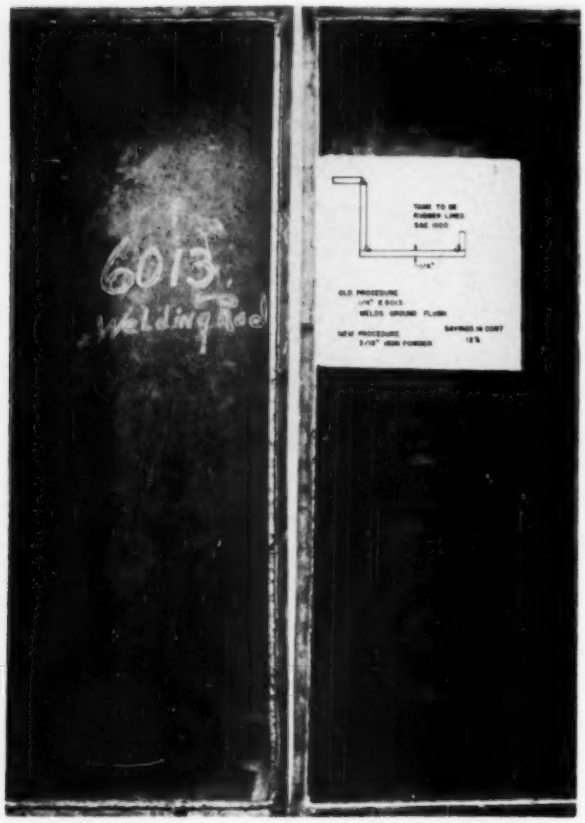


Fig. 21 All of the welds for this tank have to be ground flush for rubber lining. The improved bead shape, smoothness, bead size and lack of spatter with iron powder electrode reduced costs 12%

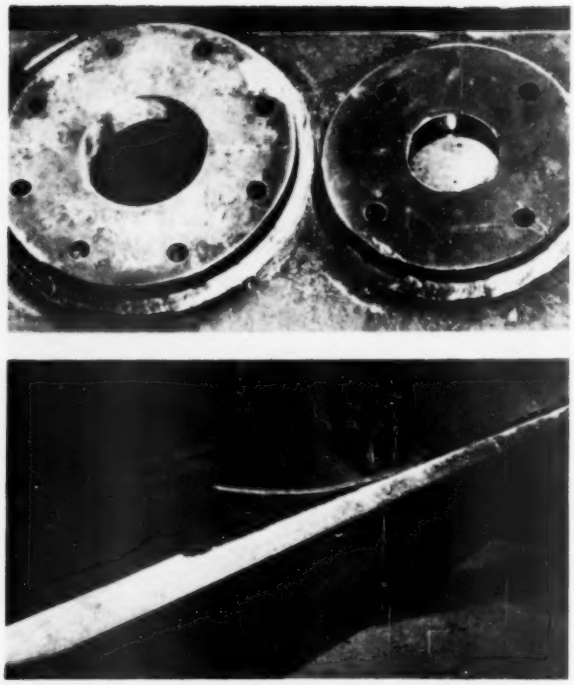


Fig. 22 These close-up views of welds on the tank shown in Fig. 21 reveal the appearance quality and ease of slag removal

miss this important development as being "nothing new."

The most convincing evidence to the contrary is obtained by actually operating these electrodes. The next best thing is visual evidence of what has been accomplished with them. The illustrations accompanying this paper present this evidence, both in laboratory specimens and production case histories.

These electrodes are having wide commercial acceptance and extremely successful application, although a few conservatives have been hesitant in their acceptance because of preconceived ideas of laboratory standards which they feel must be met before acceptance can be granted.

On the basis of this evidence, it is certain that iron powder electrodes will be marked as a development in arc welding as important as was the step from bare to coated electrodes.

The Development of Plant Welding Training Programs

Training methods used by General Motors for resistance welder maintenance men. Suggestions are made to aid others in the solution of their own operating problems

by Morris D. Thomas

PREFACE

ONE of the six basic principles that the General Motors Corp. uses as a guide throughout its entire operation is to "Train everyone for the job to be done." Since General Motors has "decentralized operations and responsibilities with coordinated policies and control" the management of each division and plant determines to what extent training is used to solve specific operating problems. Often plant personnel or supervisors are able to give the training needed and do. At other times, when requested to do so by the management of the unit involved, General Motors Institute assists in the training activity. A large number of individuals are reached each year by the programs developed and presented by the Institute to meet expressed division and plant operating needs. These individuals include supervisors, engineers, cooperative engineering students, plant technicians, skilled trades apprentices and production workers.

Last year the number of individuals trained by the Institute Personnel for the divisions and dealerships exceeded 36,000. Untold numbers were trained by their own supervisors or plant personnel.

THE WELDING GUIDE PROGRAM

The real beginning of the "Welding Guide Program" came long before General Motors Institute was called upon to participate in its development. The program had its start when men responsible for the welding operations in one of our major divisions realized that they had a situation in which training was the best approach to the solution of a specific plant problem.

Two separate and distinct conditions prompted the management to consider a training program for resistance welder maintenance men at this time. The first was a realization on the part of management that some of their welder maintenance men lacked adequate and readily available information relating to resistance welding schedules and associated problems. This situation had resulted in maintenance men using widely varying practices to maintain welding operations. In some cases, this variation in practice created additional welding problems.

In many cases when setting up a welding job the maintenance man must try a wide range of machine settings before arriving at the best welding condition. By such methods the best combination of weld settings were not always obtained. The selection of weld times that were too long, welding currents that were too high and electrode forces that were too low sometimes produced "passable" welds, but electrode tip wear increased and welding equipment life was greatly reduced.

It was realized that the welder maintenance man did the best job he knew how, but that the art of maintaining resistance welding equipment had to be replaced by the science. Management knew that if the welder maintenance man was furnished with information on how to select the best machine setting for any welding job he could set up the machines more efficiently and in less time and that the use of these settings would result in the least amount of maintenance and least number of operating problems.

The second condition which prompted management to realize that a need existed for training was the increased use of more complex controls and equipment. Management realized that it was becoming more and more essential that the welder maintenance man have a more complete knowledge of welding equipment and a better basis for solving equipment maintenance and set-up problems.

To provide the welder maintenance man with the information that he needed, Process Development Plant personnel, in cooperation with the Production Engineering Section, and Welder Maintenance Supervisors

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prepared a *Welding Guide*. In the development of this *Guide* certain information, based on what was required to solve the most common operating problems encountered in the various plants, was considered as being of the utmost importance. Only this information was included in the first edition of the *Welding Guide*. The information and welding schedules comprising the content of the *Guide* were compiled from plant experience and were verified in the welding laboratory of the division. A glossary of plant welding terms was included in an attempt to provide a common language for all who used the *Guide*.

The following criteria were established as design specifications for preparing the *Guide:*

1. The *Guide* was to be used as a welding maintenance tool by welder maintenance personnel.
2. The *Guide* was to help each man constantly in doing his job better.
3. The *Guide* was to constitute a ready reference in convenient pocketbook form.
4. The *Guide* was to relate general knowledge to specific jobs and problems.
5. The *Guide* was to be a real beginning to help solve the need of every welder maintenance man for his own source of up-to-date and correct information.
6. The *Guide* was to be revised to keep its content current.

The first edition of the *Guide* consisted of the following sections:

Section A.....Glossary
Section B.....Fundamentals of Resisting Welding
Section C.....Fundamentals of AC Electricity
Section D.....Ignitron Tubes and Contactors
Section E.....Maintenance of Electrodes
Section F.....Spotwelding with Portable Guns and Stationary Spotwelders
Section G.....Presswelding
Section H.....Projection Welding

By this time management had already invested a considerable amount of thought, time and effort in preparing the *Guide* for the use of the welder maintenance man. However, management realized that just to hand the *Welding Guide* to the welding equipment repairmen would be of little help to them since they would be unfamiliar with its use and reference value. The problem as to what information was needed by the welder maintenance man had been solved by divisional personnel. The problem as to how to effectively present this information to the welder maintenance man so he could and would use it to more effectively maintain resistance welding machines remained to be solved.

It was decided that the most effective solution was to present this information to the welder maintenance man through formal training sessions conducted in each plant by selected supervisors from the Welding Equipment Repair Activities. It was at this stage in the development of the program that General Motors Institute was called upon to assist the division in its training activity.

At the request of the Divisional Director of Training, the President of General Motors Institute assigned two men; one was the Institute Supervisor of Program Development and the other was a faculty member from the Science Department, who had both welding and plant training experience to meet with the division to determine what could be done to train the divisional supervisors who were to present the content of the *Welding Guide* to their own employees. As a result of this meeting the Institute personnel agreed to assist in training the supervisors of the welder maintenance men as trainers.

Before discussing the actual steps followed in developing the "Welding Guide Program" proper it would be best to discuss briefly the General Motors Institute approach to the development of a plant training program to meet a specific need.

First: Training is undertaken only to help the man responsible for operations use training effectively in solving a specific operating problem.

Second: The development of a training activity is started when management of the operating unit involved decides:

1. To invest the money and materials needed for the preparation of training aids.
2. To invest the time, effort and thought of those people whose experiences are needed to build a good sound training program.
3. To provide suitable facilities for training purposes.

Third: The development of a training program is carried out by a group of responsible people with technical, operating and training experience.

All of these are essential if a sound and satisfactory training program is to result.

Our experience has shown that the thinking of a group of people is much better than the thinking of one individual in the development of a plant type training program. However, it should be pointed out that just "any old group of people" will not do. The group of people brought together must pool the three kinds of experience mentioned to produce a sound training program. Again these kinds of experience are: technical experience, operating experience and training experience.

Technical experience was needed in the "Welding Guide Program" to make sure the *Guide* content was technically correct. Technical experience provides the "what" or the proper training material content. In this case it was furnished by men from the Process Development Plant, by the Production Engineering Section, by plant supervisors of welder maintenance and by welding engineering instructors from the Institute.

Operating experience was important in this group in order to be certain that the proper emphasis was placed on each phase of the training program and that the program, while offering a challenge to the maintenance man, was not over his head. The man with operating experience is familiar with the trainees. He is in the best position to know how much information and skill and what kind of attitude the trainee

must have in order to perform his job effectively. Operating experience furnishes the "how much" part of the training program. In this case operating experience was furnished by welding maintenance supervision.

The third type of experience that must be pooled by the group is training experience. Training experience is required in order to insure that the best training methods known for the job to be done are used to present the program. Training experience provides the "how" or methods of training needed to present the program. In this case training experience was furnished by both divisional representatives and faculty members of the Institute.

The reason for having all three kinds represented in the group preparing the program is that they act as a balance for each other. For example, there might be a tendency for the technician to try to make a technician out of a supervisor, or vice versa, for that matter. The man with operating experience would see that this was not done. He would know for example, that it would not be necessary to go that far in a training program to help the supervisor.

The procedure used by the group of men who prepared and presented the "Welding Guide Program" consisted of five steps. These steps could be called:

Planning Step.
Designing Step.
Developing Step.
Testing Step.
Using Step.

At the preplanning meeting the group of people who were to develop the program for "training the trainers" was determined.

In the planning step this group met:

(*a*) To determine the needs of the welder maintenance supervisor who would present the *Guide*-training program.

(*b*) To establish a program objective for training the welder maintenance supervisor for the job to be done.

(*c*) To establish the general structure of the two training programs.

At this meeting it was agreed that the needs of the welder maintenance supervisors who were to present the *Welding Guide* to their own maintenance men were:

(*a*) A complete knowledge of the content of the *Welding Guide*.

(*b*) Knowledge and skill in the techniques to be used in presenting the *Welding Guide* to their own men.

It was agreed that the objective of the part of the program for training the welder maintenance supervisor was to fulfill his needs as outlined above. It was also agreed that the pattern to be followed in training the trainer would be:

(*a*) Present the "Welding Guide Program" to him in the manner he would be expected to present it to his own men using the training aids developed for his own use.

(*b*) Discuss with him principles of learning, principles of communications, the steps in training and the use of instructor's outlines and learning aids.

(*c*) Provide ample time for his individual practice, including sufficient time for a constructive critique by members of the training group.

The second step in preparing the training program was that of design. In this step the group "made the blueprint" for the training program. Making the blueprint consisted of

1. Establishing specifications on the content to be covered.
2. Placing the emphasis on time to be spent on each subject.
3. Determining the methods of training to be used.

A part of the specifications for one section of the Welding Guide Presentation is shown below.

Sample of

WELDING GUIDE SPECIFICATIONS. Part II

OBJECTIVE:

To help maintenance personnel gain a complete understanding of the *Welding Guide* so that they can use it in solving their operating problems.

Pattern for Handling the Content in the Plant Situation:

1. Divide *Guide* into teachable units.
2. Lecture on each unit with learner following *Guide*.
3. Discuss problems in relation to unit.
4. Discuss how to use *Guide* in solving problems.
5. Provide questions at end of unit.
6. Explain what will be covered next time.

Content:

1. Introduction and fundamentals of resistance welding (pp. 1 through 11).
2. Ignitron tubes and contactors.
3. Maintenance of welding electrodes.
4. Welding with portable guns and stationary spot welders.
5. Press welding.
6. Projection welding.

INTRODUCTION TO FUNDAMENTALS OF RESISTANCE WELDING AND ELECTRICITY

Key Points:

1. Explain resistance welding.
2. Cover difference between forge weld and fusion weld.
3. Describe basic elements of resistance welding (stress current and force concentration).
4. Indicate relative importance of three major variables.
5. Show limits of these variables.
6. Define the elements of welding cycle.
7. Cover fundamentals of electricity as applied to resistance welding.
   (*a*) Define a-c and d-c current.
   (*b*) Cover difference between d-c resistance and a-c impedance.
   (*c*) Point out that contact resistance at weld point determines heat developed at weld.
   (*d*) Point out that current impedance determines power requirements.
   (*e*) Illustrate effect of cable polarity.

When the program blueprints or design specifications were completed the group was ready to proceed to the development step of the program.

In the development step on any program it is essen-

tial that persons with the correct background and the right experience are assigned as writers for the programs. In this case, men from the Process Development Plant, the Production Engineering Section and the Institute staff received writing assignments. The writers then proceed to prepare the first draft of the instructor's outline and the learning aids. It is their job to produce this first draft of the training materials by interweaving the stipulated design specifications with the results of their own creative thinking.

When the writer's first draft is completed it is reviewed. The purpose of the review is to determine if the writer has produced training material that meets the design specifications and to obtain suggestions for improvement of the training material from the review group. The review of the first draft of the training material can best be accomplished by all or part of the design group. These people representing the technical, operating and training viewpoints are the most familiar with the intent behind the design specifications since they prepared the specifications and are therefore in the best position to judge if an effective writing job has been done.

It seems almost unnecessary to say that some changes and revisions were suggested to the writers by this review group. Using the suggestions of the review group as a guide the writers now produced the test model of the training program. A portion of the completed instructor outline looked like this:

WELDING GUIDE TRAINING PROGRAM

Instructor's Outline

Session Two: Introduction to Fundamentals of Resistance Welding and Electricity

I. OBJECTIVE:

To give welder maintenance personnel an understanding of the fundamentals of resistance welding and electricity needed for their jobs.

II. OUTLINE OF CONTENT:

1. Definition of resistance welding.
2. Explanation of the three elementary variables of resistance welding, the relative importance and the limits of each.
3. Explanation of the welding cycle.
4. Explanation of the fundamentals of electricity needed to understand the principles of resistance welding.

III. EQUIPMENT

1. One set of charts as called for in this outline, WG-2.

IV. SUGGESTIONS TO INSTRUCTOR:

1. Avoid being academic or "high brow" in presenting the material in this outline.
2. It should be kept in mind that this is an introductory session. It is, therefore, important that the discussions be limited to the content of the outline as there may be a tendency to draw the instructor into subject matter which will be covered later in the program.
3. Mention terms used in the shop that have the same meaning as those given in this outline. Emphasize the fact that from now on, we will try to use the terminology given in the *Guide* to avoid confusion or misunderstanding.
4. Give group members an opportunity to ask questions and keep in mind that a clear understanding of the fundamentals of resistance welding and a-c electricity is essential to understanding and correctly using the *Welding Guide*. Do not proceed at any point unless all of the group shows evidence of understanding the content up to that time.

V. SUGGESTED TIME: 1 hour.

Instructions to Leader	Charts and Content
Define resistance welding (use *Guide* definition)	"Resistance welding is the joining of metals with the heat developed by an electric current and the force developed by a pressure unit such as an air or hydraulic cylinder." A spot weld or a projection weld are types of resistance welds which join overlapping metal pieces much as a rivet would.
Point out the difference between resistance (forge) welds and arc or gas (fusion) welds by saying—	In arc or gas welding, the metal parts are joined by melting or fusion. The surfaces to be joined are heated until they melt and flow together. When the molten metal cools, the two pieces become one. In resistance welding, the principle is the same as that used by the blacksmith not so long ago when he forged two pieces of steel together. The two surfaces to be joined are heated until they are plastic and then they are forced together under mechanical pressure until the two contacting surfaces weld.
Turn to Chart 1 and say—	Let us look at Chart 1 and see what are the three basic elements involved in the making of any resistance weld.

Chart 1. (This is a copy of Fig. 1, p. 9 in the *Guide*.)

In the testing step, the men selected as instructors and observers actually try out the program. Sometimes this is done by bringing in a representative group of the individuals for whom the program is intended and observing closely their reaction to the material presented. In this case, the test run of the training material was made when the first group of welder maintenance supervisors attended a one-week "training trainers" program at the Institute. These men pointed out during the sessions at the Institute where and how the *Welding Guide* and course content should be altered so that a more effective presentation could be made of the program to the maintenance men in the plants. The suggested revisions were made in the training materials before they were shipped to the plants and the development part of the training job was now completed. The only step left was for the trainers to use the material in presenting the program in the plants to their own welder maintenance men.

This has been done by the supervisors in plants with gratifying results. What happened as a result of this program illustrates that training is a continuing process and in a dynamic world is never complete. The pres-

entation of this training program in the plant brought to light additional operating problems and even at this time, material is being gathered for a 2nd edition of the *Welding Guide*.

All of us realize that supervisors are the key men in all organizations as far as training is concerned. Every action of the supervisor is a training activity. He transfers information or knowledge and imparts skill or "know how" to the man on the job. He effects changes in the attitudes of those around him by what he says and does. How well he performs this training function determines how great or how small are the operating problems of his organization.

It is true that a supervisor cannot always be expected to fulfill all the training needs that develop in an organization by his day to day contact with those on the job. But who in the organization is in a better position to make management aware of the existence of present and potential operating problems than the supervisor? Who else is better qualified to show management what part of these problems could be most economically solved through proper training? Who else is in a better position to secure the facts needed to convince management that training is essential? Who else is in a better position to show what tangible results are produced by training programs?

Where management is "training minded" the task of getting needed training done is far easier than where management is not "training minded." However the management of any progressive industrial organization will sponsor training activities if the supervisor properly presents evidence of a need for a training program. Evidence the supervisor might present to convince management that the organization had a specific training need could be gathered by a study of the plant's operating problems in the welding area. Indicators of training needs could be obtained by making an analysis of plant records and reports of:

1. Weld quality.
2. Weld rejects, reruns, scrap and repair.
3. Accidents and safety hazards in the welding area.
4. Plant fires, both big and small.
5. Electrode cost, waste or unusual use.
6. Productive downtime charged to equipment failure.
7. Long set-up delays.
8. Customer complaints and high product service costs.
9. Actual or potential shortage of trained welding operators or maintenance men.
10. Addition of unfamiliar processes, procedures and equipment.
11. Actual or anticipated use of more complex controls and machines.
12. Labor difficulties of all kinds.
13. Use of new specifications and standards.
14. Introduction of new products or the use of new materials in an old one.

If the facts gathered by the supervisor show that a cost factor can be reduced or plant performance can be raised to a higher level by an addition to an individual's knowledge, by an increase in an individual's skill or ability or by a modification in his attitude, a strong case for training can be built. Tangible results of the training can be shown when the before and after cost figures are compared.

The following summary is made to emphasize the major points in this presentation:

Plant training programs can only be justified when they meet specific operating needs.

Plant welding training programs do cost money, but it is more expensive not to train.

Three kinds of experience are essential in producing a sound training program. They are: technical experience, operating experience and training experience.

The five steps in the General Motors Institute approach to the development and presentation of plant welding training programs are: (1) Planning, (2) Designing, (3) Developing, (4) Testing and (5) Using.

The welding supervisor is the key man in any welding training activity.

Plant records and operating conditions can and will indicate where and what kind of training is required.

The only basis of selling management on training is for the supervisor to show that a training program is the best solution to a specific operating need.

Tangible results through improved operating performance can be shown for all justifiable plant welding training activities.

ACKNOWLEDGMENTS

Appreciation is expressed for the efforts of the following people in reviewing the paper and supplying additional information and content.

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Fisher Body Division: A. A. Alderman, Director of Training; Paton Zimmerman, Process Development Plant; and J. F. Cantalin, Production Engineering Section.

The Arc-Air Process

The Arc-Air Process is described and technical information is presented together with results of tests

by M. D. Stepath

THE Arc-Air Process is essentially the melting of metal, any metal, with an electric arc and simultaneously mechanically remove the molten metal means of a high velocity air jet external and parallel to the electrode. This process is not dependent on oxidation, and for this reason works on metals which do not readily oxidize as well as those which do.

The equipment consists of a torch with a concentric cable which carries both air and current as shown in Fig. 1. The electrode shown is usually carbon graphite though coated metal may also be used. An air line from an ordinary air compressor and the cable from a d-c welding machine are both attached to the end of a concentric cable which carries both the air and the current to the torch. The lever at the bottom of the torch controls air flow. The electrode is held in a rotating head which allows it to be set at any angle, but maintains the air steam always directed at the proper location.

The electrode usually used is a combination of carbon and graphite either plain or copper coated. There may be some question in your mind concerning the difference between carbon and graphite, and since the electrode used is an important factor in the results obtained with this process, let us take just a minute to discuss these two materials. To begin with, carbon is a product of pulverized calcined coke mixture with a binder, extruded and baked for several days at about 1800° F in a closed oven. Graphite receives further baking at a higher temperature in an electric oven and is therefore usually more expensive.

Table 1—Comparative Properties

	Carbon	*Graphite*
Structure	Amorphous	Crystalline
Density, g./cu cm	1.55	1.59
Hardness	Hard	Soft
Resistance to abrasion or erosion	High	Low
Oxidizing temperature	350–500° C	400–650° C
Rate of oxidation	High	Low
Electrical conductivity (relative)	1	4
Thermal conductivity at 1000° C (relative)	1	30

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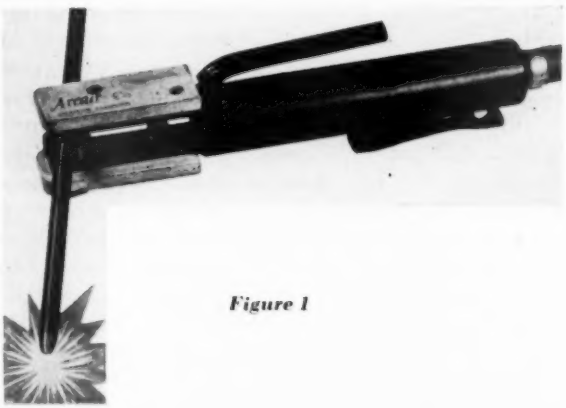

Figure 1

Table 1 shows the comparative properties of the two materials. Notice that one substance is amorphous while the other is crystalline. There is some difference in density. One is hard while the other is soft. One has high resistance to abrasion or erosion and the other low. Graphite has a higher oxidizing temperature and a lower rate of oxidation and its electrical as well as thermal conductivity is higher. In this process it is desirable to have an electrode which is hard with high resistance to erosion. On the other hand a high oxidizing temperature and low rate of oxidation are advantageous, while high electrical conductivity and low thermal conductivity are desired. This means that the best electrode for the process is that combination of carbon and graphite which, by a proper blending of the two materials, gives the properties required.

The electrodes are available in both copper coated and plain types. The plain electrodes are cheaper, use slightly less current and start a little easier. The copper coated electrodes last longer, carry higher current and maintain their original diameter which means that the width of the groove made is more uniform. They also radiate less heat which increases operator comfort and torch life.

An ordinary d-c welding machine with reverse polarity is used. The polarity may surprise you; however, straight polarity is not effective with this process. The current depends on the size of the electrode and varies from 70 amp on $^5/_{32}$-in. to 600 amp on $^1/_2$-in. electrodes. Although the higher the current density,

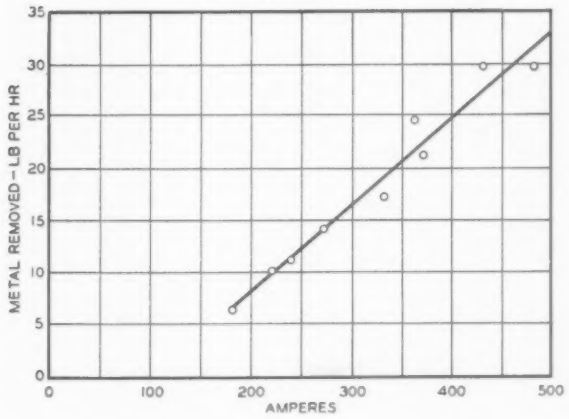

Figure 2

the more efficient the process becomes as shown in Fig. 2 which was made up for $^{3}/_{8}$-in. plain electrodes.

The necessary air is obtained from an ordinary compressor. The torch is designed to operate at 90 to 100 lb pressure which is the usual line pressure in most shops, and since this is not a critical value, no regulator is needed.

Figure 3

Figure 4

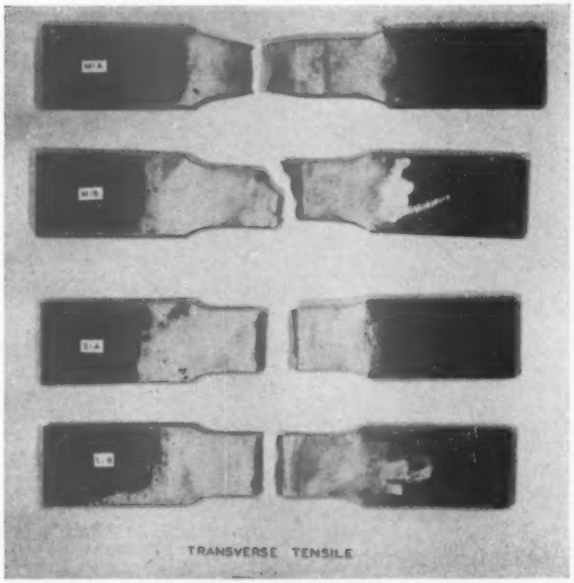

Fig. 5 Carbon arc gouging

The torch is used by holding the electrode at a leading angle and striking an arc between the electrode and the material to be cut as shown on Fig. 3. The air blast is directed immediately behind the point of arcing, and the electrode is pushed forward at a rapid rate with the air jet on continuously. The depth of the groove is determined by the angle of the electrode and the speed of travel.

Figure 4 shows the quality of the cut produced. Note how clean and smooth it is. There is some carbon pickup, but this is confined to a very thin zone, about

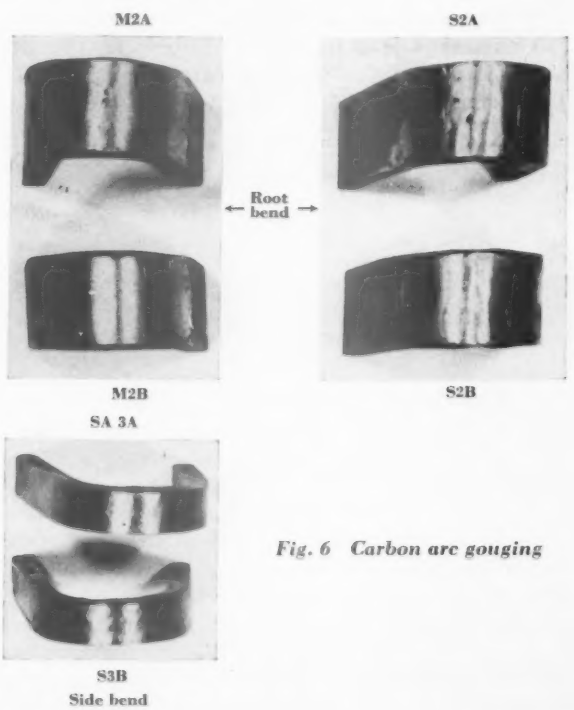

Fig. 6 Carbon arc gouging

Figure 7

0.006 of an inch thick and when welded over, the weld penetration exceeds this depth resulting in a dissipation of the carbon and only a slight increase throughout the weld metal. In most work, this is not detrimental but if removal is considered necessary a slight amount of grinding before welding will completely remove the condition because it is right on the surface.

A number of tests have been run to determine the physical properties of welds made over this surface. The results of one which are shown in Table 2.

Table 2

Transverse tensile tests

Spec. No.	*Type electrode*	*Tensile strength, psi*	*Fracture location*	*Remarks*
X1A	19/9-4Mn	66,000	Base metal	No gouging
X1B	19/9-4Mn	65,700	Base metal	No gouging
S1A	19/9-4Mn	58,950	Weld metal	Gouged root
S1B	19/9-4Mn	60,100	Fusion zone	Gouged root
M1A	E-6010	65,300	Base metal	Gouged root
M1B	E-6010	66,800	Weld metal	Gouged root

Figure 5 illustrates transverse tensile specimens. It is noted that the tensile strengths of the S1A, and S1B specimens are lower than desired, and that the fracture occurs at the weld. However, it was noted that weld defects were present which may have contributed to this lower strength.

Weld metal tensile test

Tension test of the all weld metal specimen indicated:

Tensile strength, psi	94,450
Yield point, psi	76,850
Elongation in 2 in., %	34.0
Reduction of area, %	39.4

This indicates satisfactory physical properties for 19/9-4Mn weld metal deposited over a carbon arc gouged surface.

The tensile specimens are shown in Fig. 5. Both side- and root-bead specimens were made in this test and are shown on Fig. 6.

In another test, plates containing V grooves were welded under identical conditions and then for comparison the roots of some were chipped while others were gouged with the Arc-air torch. Transverse root-bend specimens in this instance showed no difference between the chipped and gouged plates.

Because of the small area the metal being cut is instantly brought to the molten stage and speed of travel is very rapid, the surrounding metal does not reach a very high temperature and there is little distortion or crack propagation during the operation. In order to compare the temperature rise with that caused by oxy-acetylene gouging, a groove was cut in a 6-in. round steel plate, $^3/_4$ in. thick with a pyrometer attached to the back. After a 1-min gouging interval, the plate was still only 250° F when the Arc-air torch was used. On the other hand, a similar plate was 600° F when oxy-acetylene gouging was used. After two minutes the temperature was 450° F with Arc-air, but 1000° F with the oxy-acetylene gouging.

The speed varies somewhat with individual shop conditions, such as operator technique and the current used. To give a general idea, a groove $^3/_8$ in. wide and $^1/_4$ in. deep is usually cut at about 3 fpm or just about as fast as the operator can move. In order to compare speed and cost with chipping, two blocks of 20 carbon steel were grooved as shown in Fig. 7. The blocks were 7 in. square and 8 in. long,

Figure 8

Figure 9

and the groove was $2^1/_4$ in. deep. The one on the left was made with the Arc-air torch in 26 min, and the one on the right was chipped which took $1^3/_4$ hr or four times as long and, in addition, four chisels required sharpening. On hard materials or those which work hard, the difference is much greater.

The cost of operating the Arc-air torch of course depends on the size of the electrode, the current and the operator technique used. It is roughly $1.50 per hour exclusive of labor, using $^3/_8$-in. electrodes.

Figure 8 shows the torch being used to condition a large casting. Its most common use in foundries is to remove defects and excess metal. However, in some cases, it has been used to cut alloy steel as shown

Figure 10

Figure 11

in Fig. 9. In this case, the pattern was incorrectly made and a section about 1 in. thick had to be removed back to the scribe line shown.

Many pressure vessel fabricators are using Arcair to remove weld defects as shown in Fig. 10. Fabricators of mild steel plate are using the torch to prepare the edges for welding as shown in Fig. 11. This picture was taken in a barge-yard where barges were being built in the inverted position. The plate was erected with square edges and tacked, then a bead of weld metal was run along the seam on the inside. Next the Arcair torch was used to groove out the seam to sound metal preparing both plates simultaneously and eliminating handling material to and from a burning table. Some fabricators claim they save as much as 50% of their fabrication cost with this method.

This torch is also used to cut stainless steel, both in fabrication and maintenance work. It can be used to remove hard surfacing as well as cutting through stainless steel welds which attach hardened inserts. In

Fig. 12

one instance, the hard surfacing at oil well tool joints had to be removed in order to resurface the joints with new material. Work was being done by grinding which took 8 hr per joint. By use of the Arcair Torch the time was reduced to 15 min.

Although the action is slower and rougher than on steel, this torch can be used on cast iron or on copper alloys.

It is also excellent for removing fillet welds. On a recent job of fabricating trash gates for the McNary Dam, a change in plans required the removal of 167 cross members as shown in Fig. 12. This meant cutting out fifteen-hundred $4^1/_2$-in. double fillet welds while leaving the members of the frames intact for rewelding. The job was started by chipping, but by use of the Arcair Torch, it was reduced from 12 man-days to 2 man-days. Other typical maintenance jobs, are removal of stainless steel liners from fractionating columns, repair of railway rolling equipment and track work and cutting extremely light gages of metal where distortion is important.

Silver Brazing of Refractory Metals

Methods which may be used in overcoming difficulties in silver brazing hard to braze metals and alloys

by C. H. Chatfield

INTRODUCTION

SILVER brazing alloys may be used to join practically all metals except aluminum and magnesium base alloys and those alloys melting below the temperature range at which the silver alloys flow. There are, however, a number of metals and alloys which for various reasons are difficult to braze with the standard procedures, and it is the purpose of this paper to discuss some of these materials and to point out the methods used to overcome the difficulties.

A primary requisite for obtaining a strong bond is that the brazing alloy must wet and at least superficially alloy with the base metal. The failure to wet the surface may be the result of films, usually oxide, on the base metal or it may be the incompatibility of the brazing alloy with the metals being joined. In the first instance, the problem is to develop a flux capable of removing the film so that the brazing alloy is in direct contact with a clean base metal surface. The second case may involve the addition to the brazing alloy of constitutents which will promote alloying with the base metal.

Another problem frequently encountered is that of brazing precipitation hardening refractory alloys where the brazing procedure not only must overcome the refractory oxide film, but must be selected to fit into the heat treatment required to obtain the desired physical properties in the base metal. This may be simply a question of selecting the brazing alloy with suitable thermal points or it may develop into the determination of the proper sequence of brazing, solution treatment and precipitation hardening operations to get the desired results.

ALUMINUM-BRONZE

The usual silver brazing flux consisting of boric acid, alkaline borates and fluorides does not work in brazing aluminum bronze. When such a flux is used black

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residues are formed on the surface of the aluminum bronze which interfere with the wetting of the surface and the flow of the brazing alloy. The addition of 15% zinc chloride to the standard fluxes will eliminate the formation of the black residue and permit the making of strong joints.

Frequently it is necessary to braze aluminum bronze to steel. The zinc chloride addition to the standard flux destroys the fluxing action on steel. A flux which will work on steel as well as on the aluminum-bronze is required. Such a flux consisting of a mixture of borates, fluorides and chlorides has been developed and is commercially available. With this flux aluminum bronze can be brazed not only to carbon steels but also to the stainless steels.

Fluxing is only part of the problem of brazing aluminum-bronze to steel. It has been found that the contamination of silver brazing alloys with a small fractional percentage of aluminum will prevent the formation of a satisfactory bond on steel. A silver brazing alloy containing a few thousandths of a percent of aluminum will wet and flow on the steel when first applied. After wetting, continued heating for a few seconds results in dewetting and the brazing alloy can be peeled off the surface of the steel with ease. The cause for this is not clearly understood but it is probably the result of a deposition of an aluminum oxide film at the interface of the joint. Contamination of the brazing alloy can occur by solution of aluminum from the bronze and diffusion through the molten brazing alloy to the steel surface. The brazing cycle should, therefore, be kept as short as possible.

The effect of the contamination of the brazing alloy by aluminium can also be avoided by the use of a brazing alloy containing nickel. The aluminum which dissolves in the brazing alloy reacts with the nickel and in this manner the formation of the detrimental film on the steel surface is prevented.

An alternative methods which has been successful is the use of a copper shim in the joint. In this method a sheet of brazing alloy is placed on each side of the copper; the copper is brazed to the steel on one side and to the aluminum-bronze on the other. The copper acts as a barrier preventing the diffusion of the aluminum to the steel. The special flux is still required in order to bond the aluminum-bronze alloy to the copper. Copper with a brazing alloy coating on both sides is available commercially and this appreciably simplifies the assembly of the joint to be brazed.

BERYLLIUM-COPPER

The best physical properties of beryllium copper are obtained by quenching after a solution treatment at 1450–1500° F followed by a low temperature anneal at 525–600° F to produce precipitation hardening. The original recommended practice for brazing this alloy was to use a brazing alloy which flowed in the temperature range of the solution treatment so that the brazing and solution treatment could be combined.

This procedure has disadvantages as the solution treatment normally requires longer times than is desirable from a brazing standpoint. When the assembly has to be torch brazed two operations are required and with the use of a high melting brazing alloy there is always danger of overheating and partial fusion of the beryllium copper unless extreme care is taken during the torch heating. Beryllium oxide film formation will also be more objectionable at high temperatures.

Most beryllium copper is supplied to the customer in the solution treated condition. It has been found[1] that beryllium copper in this condition can be brazed at temperatures of 1200 to 1300° F and then precipitation hardened at 600° F to develop the hardness and spring properties comparable to those obtained with the higher brazing temperatures. It is not possible to retain cold work hardness through the brazing cycle. The usual procedures for brazing can be followed, the primary requisite being that the brazing cycle be kept as short as possible. After the joint has been made the assembly should be quenched as soon as the brazing alloy has solidified.

Joint strengths up to 90,000 psi, approximately the proportional limit of the beryllium copper (precipitation hardened—not cold worked), have been obtained on brazed and age-hardened butt joints.

To obtain this strength consistently a considerable degree of skill and care is required. Flux entrapped in the joint is the principal cause of poor joint strength. Frequently the brazing alloy will flow normally on the surface but on breaking the joint it is found that the alloy has not flowed entirely through the joint. This is largely a matter of fluxing. Beryllium oxide is refractory and an active flux is required to get maximum oxide solubility at the brazing temperature.

Beryllium copper is occasionally brazed to steel and if sufficient beryllium diffuses into the brazing alloy the same type of dewetting as occurs with aluminum-bronze has been observed. In such cases the use of a nickel-bearing brazing alloy is recommended.

17–7 PH STAINLESS STEEL

The 17–7 pH stainless steel is a precipitation hardenable steel. The treatment for this material requires a transformation heat treatment at 1400° F for a period of 30 to 90 min, cooling to 60° F and reheating to 950–1050° F for 90 min.

A procedure which has given excellent results is to heat treat at 1400° F, cool to 60° F, torch braze with a brazing alloy flowing below 1400° F, cool to 60° F and finally reheat to 1050° F. The hardness of the steel will closely approach that of the hardness obtainable without the insertion of the brazing operation. It is essential, however, to keep the brazing cycle as short as possible.

It has also been found that the transformation heat treatment and brazing operation can be combined, provided the 1400° F anneal is shortened to 30 min.

The joint is then cooled to 60° F and reheated to 1050°. Shear strengths of as high as 43,000 psi have been developed on 0.050-in gage stock lapped 0.200 in. Laps of approximately $^3/_8$ in. had approximately 10% higher breaking loads but the assemblies broke in the steel without failure in the joint. The steel had a tensile strength of about 185,000 psi. Easy-Flo No. 3 was used in making these joints.[7]

CHROMIUM CARBIDE

Chromium carbides have presented a variety of problems in wetting and these have varied with the compositions and processes by which the carbides were manufactured. Certain chromium carbides in the as-sintered condition have a nickel-rich surface that is relatively easy to wet by conventional means. When the original surface is ground off, the underlying chromium carbide may be very difficult to wet. There are several approaches that may be used, viz.: (1) Use Ag-Cu-Sn-Mn alloy; (2) use flux with 1% of powdered silicon metal admixed. With the silicon flux, standard brazing alloys may usually be used, but the combination of special brazing alloy and special flux may be required for a particularly refractory grade of carbide. On the other hand, the special Ag-Cu-Sn-Mn alloy often suffices with standard flux.

Another alternative is the use of 85% Ag – 15% Mn with standard high temperature flux. This has been able to wet any chromium carbide thus far encountered; the temperature, however, may be objectionably high for some applications.

CHROME-IRON ALLOYS (STAINLESS STEEL)

The problem of brazing the nickel-free stainless steels is not one of obtaining a strong joint—almost any of the silver brazing alloys can be used for that purpose—but of making a joint which will resist corrosion in humid atmospheres.

The bond between a nickel-free silver brazing alloy and a nickel-free stainless steel may fail in a few days in such a mild corrosion medium as humid air or running tap water. For this reason many have mistakenly attributed the difficulty to poor wetting during brazing.

It has been shown[2] that the use of a conventional nickel-bearing silver brazing alloy will reduce the corrosion and confine the corrosion to the periphery of a filleted joint, but will not entirely eliminate it.

The formation of a corrosion-resistant bond on nickel-free stainless steel appears to depend upon the deposition of a nickel-rich layer (from the brazing alloy) over the entire area covered by the brazing alloy. The conventional nickel-bearing brazing alloys only partially produce this condition.

One type of alloy has been developed which will form such a nickel-rich layer, viz., 63.0Ag – 28.5Cu – 6Sn – 2.5Ni. This alloy has a flow point of 1475° F. While it wets the surface of stainless steel very well, it is sluggish and has poor spreading properties. It should, therefore, be preplaced wherever possible to avoid the necessity of flowing long distances. Conventional heating and fluxing procedures can be used in applying the alloy.

MOLYBDENUM

Molybdenum is another metal which is difficult to braze with the usual brazing alloys. It has been found that the addition of phosphorus to the silver brazing alloys will permit molybdenum to be brazed. As little as 0.25% phosphorus produces a marked improvement in the wetting of the molybdenum surface, but approximately 1% of phosphorus is required to obtain the maximum strength of joint. Higher phosphorus contents are permissible and the copper-phosphorus or the silver-copper-phosphorus alloys containing up to 7% phosphorus have been successfully used.

With the use of phosphorus-bearing alloys no special flux is required other than the usual silver brazing fluxes.

Molybdenum-bearing alloys, such as some of the high-speed steels, are also difficult to braze. In this case, phosphorus-bearing brazing alloys cannot be used because of the brittle iron phosphide formed at the interface of the joint. Here it has been found that the addition of about 5% of an alkali hydroxide to the usual fluxes materially improves the flow of the silver brazing alloys, although the joint strengths obtainable will not equal the strength of silver-brazed tungsten high-speed steels.

TITANIUM AND ZIRCONIUM

The growing use of titanium has created a demand for methods of joining titanium. As the procedures for brazing titanium work equally well for zirconium, the two metals are discussed together.

There are two reasons which make titanium difficult to braze; first, the oxides of titanium are refractory and not readily removed by fluxing, and second, the formation of brittle metallic compounds by reaction of the titanium with the constituents of the brazing alloy.

The problem of fluxing has been solved and a flux[3] is now commercially available which will clean the surface of titanium so that the silver brazing alloys will wet and flow. It is a mixture of alkali metal chlorides and acid fluorides. Borate fluxes cannot be used. They completely prevent wetting.

The formation of the brittle compounds at the interface of the joint cannot be entirely avoided, but can be controlled to some extent by keeping the time the titanium is in contact with the molten brazing alloy to a minimum. Butt joints have been obtained on $^3/_8$-in. diam titanium rod which averaged 45,000 psi.

An investigation by Smith and Yerkovich[4] gives an excellent summary of the strength, stress-rupture and fatigue properties of lap joints of titanium sheet brazed with silver brazing alloys.

Embrittlement in the titanium joints can be avoided

by brazing with fine silver as described in a paper by DeCecco and Parks.[5] In this procedure a flux containing a metal depositing reagent, such as silver chloride, is used. Silver is one of the few metals which will alloy extensively with titanium without the formation of a very brittle intermetallic compound. A compound is formed, but it has some ductility.

TANTALUM

Tantalum has been brazed with silver brazing alloys with the use of the flux developed for titanium. The joints and the tantalum are usually brittle.

Copper-gold alloys containing less than 40% gold have also been used for brazing tantalum.

In any case there is a strong likelihood of gas embrittlement of the tantalum.

ALUMINUM TO COPPER

With expanding use of aluminum there has been a demand for a method for joining aluminum to copper.[6] The direct brazing of aluminum to copper with the aluminum-silicon brazing alloys is unsatisfactory because of the low melting temperature and extreme brittleness of the aluminum-copper eutectic composition which forms in the process.

Strong, ductile joints have been made by "tinning" the copper with a silver brazing alloy and then brazing the "tinned" surface to aluminum with the aluminum-silicon alloy. The silver brazing alloy coating should be not less than 0.005 in. thick to prevent the diffusion of the aluminum to the copper. In lieu of the silver brazing alloy coating, the copper may be silver plated or a sheet of silver may first be brazed to the copper. The metal barrier layer between the copper and the aluminum must in all cases be of the order of 0.005 in. thick. In brazing the silver coated copper to aluminum an aluminum brazing flux must be used to dissolve the refractory aluminum oxide film. If a borate flux has been used to join the silver to the copper, the residue should preferably be removed from the silver surface before the aluminum brazing is done.

Among the silver brazing alloys that may be used as barrier layers between the aluminum alloy and the copper, high silver, cadmium-free alloys make more ductile joints than the low-melting Ag-Cu-Zn-Cd alloys. A particularly apt choice is 65Ag – 20Cu – 15Zn or 75Ag – 25Zn. When a fine silver shim is to be used as the barrier layer it may best be attached to the copper with the first of the above-mentioned alloys. There will be less tendency to remelt the joint during the subsequent aluminum brazing step than if the silver had been applied with the lower melting Ag-Cu-Zn-Cd alloy.

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Some Practical Considerations in the Application of Tungsten Arc Welding

Welding procedures for welding similar and dissimilar metals including type of gas, voltage, current, gas flow and speeds

by H. A. Huff, Jr.

INTRODUCTION

THE welding of similar and dissimilar metals with the nonconsumable tungsten electrode, using either helium, argon or a mixture of both inert gases as a shielding medium, presents problems that require special consideration.

Study must be given to the advisability of manual welding and product or arranging semiautomatic or fully automatic setups for the job under consideration. High production is the primary reason for using mechanical means involving expensive fixtures. However, one must consider quality, even though production requirements may not be high. Other factors to be considered are the welding equipment available in the shop, composition of the metals to be welded, material and finishing costs, welding speeds obtainable and their effect on the product involved.

Consideration will be given in this paper to proper welding procedures which involve arc voltages, current, gas flows, and welding speeds. Conditions which indicate the need for suitable fixtures for the job, whether it is manual or mechanized welding, will also be discussed.

INERT-GAS-SHIELDED ARC WELDING

The inert-gas-shielded tungsten-arc-welding process is well established in all industries where metals are joined by welding. Its greatest use has been where rigid requirements must be met. High production of quality welds in the "hard-to-weld" metals—Inconel, stainless steels, killed steels, aluminum, Everdur, copper, nickel, Monel—has increased the demand for the use of this process. Welding speeds are obtained today that were a welding engineer's dream until a few years ago.

The major advantages of this process are flux-free welding, no interpass cleaning, less distortion and welds free of porosity. Moreover, it produces quality welds without filler rod in certain types of work. Because of the narrow heat-affected zone, stainless steel sheets as thin as 0.010 in. have been welded successfully. The successful welding of extremely thin sections generally calls for automatic welding equipment and precision-built fixtures.

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INERT GASES: HELIUM-ARGON

Heretofore, gas flow rates were never generally established by actual flow but by surface appearance and arc stability. Today, greater thought by equipment manufacturers and users of the equipment and gases is being given to the problem of getting good results at a lower flow of gases. With this in mind, it follows that more consideration is given to automatic equipment which will help to cut the gas bill.

The flow rates required for a comparable gas coverage with helium are about twice that of argon. However, increased welding speeds compensate (when using helium) for the cost of the additional gas used. Figure 1 shows Incoloy tubing which was Heliwelded at a speed of 185 ipm. Tube *A* shows uneven penetration with argon. Tube *B* reveals uniform penetration with helium. In addition, greater arc stability is obtained with helium gas. High-speed tube welding in continuous tube mills, now performed almost exclusively by the inert-gas-shielded tungsten-arc process applied automatically, is a good example of speed compensating for the cost of larger gas flows when using helium. Speeds of 10 to 15 fpm are obtained in welding stainless steel and Incoloy steel. Refer to Figs. 2 and 3. In aluminum tube fabrication welding speed of 50 fpm and better are obtained.

Various mixtures of both gases have been investigated in industry. It has been found that a mixture of 65% helium and 35% argon have about the same characteristics as straight argon in d-c straight polarity welding In other words, arc voltage versus arc length is substantially the same. In another instance, where balanced a-c is employed for welding aluminum tubing,

Fig. 1 (Left): Welded with use of argon shield; (right): helium gas

a mixture of 70% helium and 30% argon works as well as 100% argon.

Helium gas is often referred to as a more costly gas than argon, not only in terms of cents per cubic foot of gas but in terms of consumption. Helium gas actually costs less and, despite the fact that double the amount of helium is required, additional gas costs are offset by faster welding speeds which, in many cases, are tripled.

In the welding of stainless steel—sheets and tubing in continuous tube mills where high speeds are possible—better quality welds with narrower heat-affected zones are consistently achieved. Moreover, because of higher welding speeds less distortion results.

The use of mixed gases, 70% helium and 30% argon or other mixtures favoring helium gas, is a growing practice based on results which indicate that certain jobs profit from the characteristics of both gases.

In the welding of stainless steel sheet, helium offers definite advantages. It provides a hotter arc than argon and makes faster travel speeds possible.

When the fused area of a bead is plotted against the energy input a different relationship exists for each travel speed. Less energy is required to fuse a given area when the travel speed is high. The reason for this effect is that a slow travel speed results in more heat soaking into the plate material without raising it to the melting point. This applies in particular to stainless steels. Other materials having different heat conductivities, melting points and specific heats will have different absolute values, but the principle of improved weld quality resulting from faster welding speeds still applies in varying degrees.

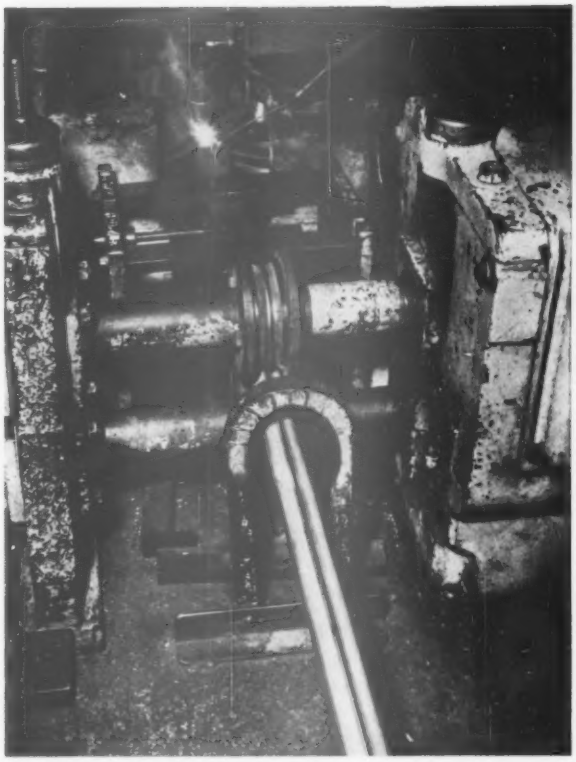


Fig. 2 After the flat, cold-rolled stainless steel is shaped into a tube, the butted edges are welded together. Here you can see 1 1/2-in. by 0.120-gage, type 304 stainless tubing being guided by rollers underneath the automatic Heliweld machine

Fig. 3 Close up of automatic Heliweld nozzle

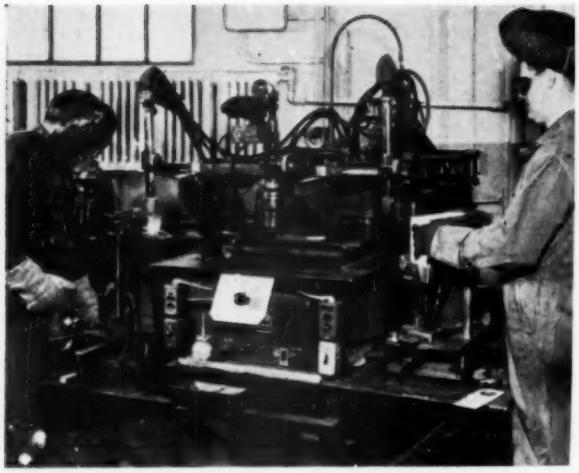


Fig. 4 Heliwelding aluminum case boxes using No. 10 Planograph with two Heliweld holders using magnetic traces—Helium gas—d-c straight-polarity thoriated tungsten electrode

To obtain the same degree of penetration with argon that is obtained with helium gas, one must use at least 20% or better amperage ratings. Even then (with argon) wider heat-affected zones are created and the contour of the fusion area widens, resulting in a need for addition of filler wire. Speeds are not increased even though amperages are higher. This condition can lead to sagging of the weld metal if no backing bar is used or if the relief in the backing is too deep or wide.

Of great importance where gas flows are concerned, in order to conserve on consumption, is the distance of the tungsten electrode beyond the gas nozzle, the gas nozzle orifice diameter, arc voltage and the effect of air currents.

Fig. 5 Close-up of smooth, high-quality welds on aluminum case, revealing rectangular seam and longitudinal seam

Fig. 6 Automatic Heliweld head with wire feed attached

In the welding of aluminum at high speeds, helium gas of high purity is the important factor. Good cleaning of the metal before welding is also essential. Not only will the use of helium gas produce good quality welds in aluminum, but it helps to eliminate tungsten inclusions (from the electrode) in the weld. Figures 4 and 5 show a machine setup and a close-up of an aluminum case box, respectively. The use of thoriated tungsten electrodes instead of standard tungsten on this job also contributed to the excellent results.

TUNGSTEN ELECTRODES

Arc distances have a definite effect upon current values, penetration and consistently good results in terms of weld quality. The longer arcs result in longer welding time to secure good fusion and penetration. Longer welding time usually means a larger fusion zone and distortion. Precision control of arc length is important too.

The above requirements are readily met with automatic arc voltage control offered by the automatic Heliweld Head (See Fig. 6.) Another important phase of the operation is the use of the best tungsten electrodes. It has been established that thoriated tungsten electrodes are well designed for this application. When used with d-c, straight polarity, and helium gas on aluminum (or in the welding of any metal for that matter), thoriated tungsten offers the following advantages: (1) they remain colder at higher current ranges, (2) contamination is practically eliminated, (3) they do not deteriorate or melt as readily as other types of tungsten electrodes, (4) they have better electronic emissions, and (5) in touch starting of the arc they do not "freeze."

Both pure tungsten and thoriated tungsten have about equal values with a-c welding current in welding aluminum. However, there is another tungsten electrode in the field today which contains zirconium.

Fig. 7 High-frequency arc-starting, d-c welding of stainless steel

Reports indicate that it does have an advantage when welding aluminum with a-c current.

To prolong the life of all types of tungsten electrodes good shielding with the inert-gas atmosphere is essential *before* starting the arc (by purging the line), during welding and when finished with welding. While in the high heat range, even though welding is over, the electrode must be protected by the shielding gas. Here again is an important reason for selecting and using automatic arrangements for controlling gas flows.

Touch-starting to establish the arc, either with a-c or d-c welding current, may be eliminated by the use of high frequency remotely controlled by hand or foot switch. Figure 7 shows operator with hand switch using high-frequency arc starting in the d-c welding of stainless steel.

Approximate current carrying capacities of both pure tungsten and thoriated tungsten (thoria content approximately 1%) are listed in Table 1.

Operating differences between thoriated tungsten electrodes containing 1 and 2% thoria are difficult to measure by laboratory standards. However, field reports on some applications indicate that 2% thoriated tungsten electrodes are preferred. This may be true when welding silicon steel laminations used for rotors and stators in the manufacture of electric motors.

No matter what the thoria content of the tungsten electrode, it will not overcome deficiencies in either equipment design or insufficient gas coverage. The latter plays as important a role in getting the best results as the electrodes.

Table 1

Electrode Diameter in (inches)	Gas Nozzle Orifice Size in (inches)	Gas Flow in Cubic Feet per Hour	Direct Current in Amperes					Alternating Current in Amperes			
			Reversed Polarity		Straight Polarity			Standard Tungsten			
			Standard Tungsten Electrodes		Standard Tungsten Electrodes		Thoriated Tungsten Electrodes	Balanced A-C Transformer		Standard Transformers Supplied with Continuous High-Frequency	
			Helium	Argon	Helium	Argon	Helium or Argon	Helium	Argon	Helium	Argon
.040	1/4 5/16 3/8	8 - 12	up to 10	Not used	up to 50	up to 65	12 - 100	up to 25	up to 35	Not used	up to 30
1/16	1/4 5/16 3/8	10 - 16	10 - 20	Not used	40 - 125	65 - 150	20 - 190	20 - 60	30 - 85	Not used	20 - 115
3/32	3/8 or 1/2	12 - 20	20 - 35	Not used	125 - 225	140 - 280	35 - 325	50 - 100	75 - 130	Not used	100 - 185
1/8	3/8 or 1/2	15 - 30	25 - 50	Not used	200 300	250 - 375	50 - 475	75 - 175	100 - 200	Not used	150 - 225
3/16	1/2	15 - 30	30 - 75	Not used	250 - 350	300 - 475	None this size	150 - 240	175 - 300	Not used	200 - 340
1/4	1/2	15 - 30	40 - 125	Not used	300 - 475	420 - 475	None this size	200 - 330	275 - 400	Not used	300 - 400

NOTE: This chart should be used only as a guide. Conditions of any application may make it necessary to change these figures slightly.

Mixtures of 70% helium and 30% argon, or 80% helium and 20% argon have been used successfully for both A-C and D-C Heliwelding.

Standard tungsten electrodes should be used with currents as close to their maximum current capacity as is practical, but not over.

WELDING CURRENT

There are several welding machines used today with the inert-gas process for both a-c and d-c welding. Taken as a whole they perform equally well under regulated conditions. First, there are d-c motor generator sets, then the d-c rectifier machines. For a-c welding there are those with continuous high frequency and those which offer balanced a-c. The inert gas to be used with any one of these machines should be considered not only from the standpoint of gas costs but from the standpoint of penetration, welding speeds, current costs, maintenance and current changes due to primary power loss.

A d-c motor generator has one advantage over the present d-c rectifier: if a line voltage drop occurs in the neighborhood of 5 to 10% no noticeable effect takes place. With a rectifier type machine, the drop will affect current output and, in most cases, particularly where light-gage material is being welded, have an undesirable effect on the weld quality. However, the rectifier type has other points in its favor. Among these are lower maintenance costs and less demanding heating conditions than those which characterize the use of motor generator sets.

In the inert-arc process (a-c welding), a rectifying action is inherent in the arc which causes a sizable d-c component to flow through the circuit. Unless this d-c component is eliminated, an unstable arc and overheating of the welding transformer will result. With the d-c component blocked, more heat is put into the work, allowing deeper pentration, a more stable arc and faster welding speeds than otherwise for the same current.

The d-c component and its inherent disadvantages can be prevented by means of a group of condensers in series with the welding leads which permit the welding current to flow but eliminate the d-c component. This leads to prevention of overheating of the welding cables and the welding machine.

The other type of a-c welder used for inert-gas welding employs a spark gap oscillator. Welding arcs of low-current density employ continuous high frequency to stabilize the welding arc. The spark gap is part of a resonant circuit in series with the primary of an air core transformer whose secondary is one welding lead. This circuit, to perform satisfactorily, has to produce a high-frequency current across the arc gaps. This helps to ionize the arc gap and makes it easier to weld with low current.

There are some advantages with the circuit just described. If continuous high frequency is used, a clean pool is obtained when welding with argon on aluminum with the low open-circuit a-c voltages usually employed with this type of equipment.

Another disadvantage of the use of continuous high frequency is the interference it has with radio communication and broadcast wave-length bands. The spark-gap in continuous use acts as a small radio station which sends out static in every direction. This is a problem and one which is hard to eliminate by shielding out the source. However, in some instances, industrial plants are in themselves shields—because of pipe, electrical and iron beam installations. These filter out most transmission of static by the high frequency.

What we term balanced a-c type inert-gas welders are those which make use of a series capacitators to block out the d-c component of welding current. They only employ high frequency to establish the arc. When the arc is established, the high frequency is cut out. With this type of machine either argon or helium may be used or mixtures of both. The choice will be to use the gas or mixture utilizing different characteristics to obtain the results desired. Figure 8 shows balanced a-c current.

To eliminate the d-c component with a-c welders, using continuous high frequency, a series of batteries with sufficient current rating can be connected with the welding cable. This procedure can also be applied to any a-c transformer with auxilliary high-frequency spark-gap oscillator. In the latter case it is necessary to use capacitators to filter out any feed-back of high frequency into any equipment connected to the same power source such as the electric fan. This is not, however, recommended practice because, as a rule, the primary and secondary coils are not sufficiently

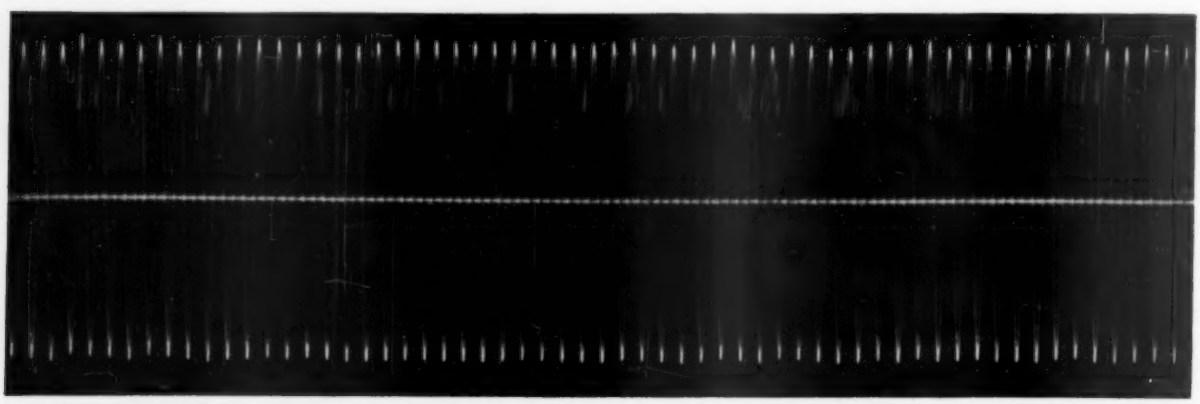


Fig. 8 Oscillogram of the arc current supplied by a balanced-wave, capacitor-stabilized inert-gas-shielded arc welder

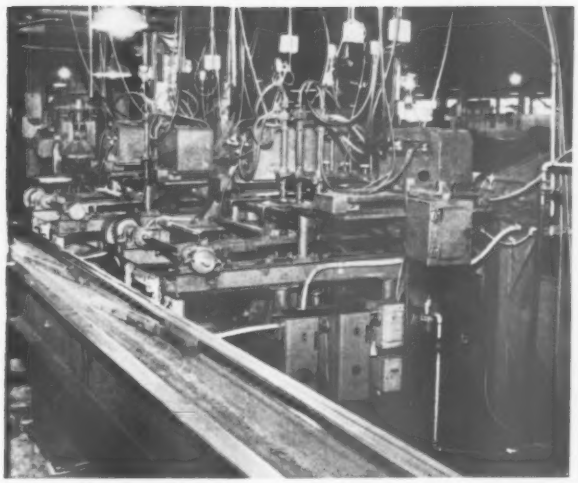


Fig. 9 Spark-gap oscillators in banks of threes for starting d-c arcs simultaneously

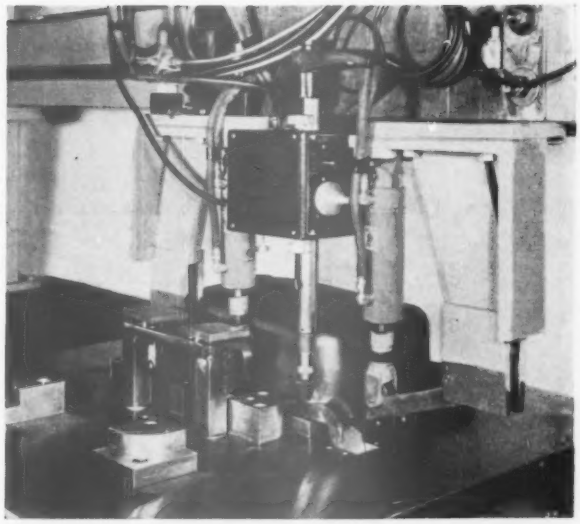


Fig. 10 Arc-starter for establishing the arc by the touch start method

insulated to withstand a heavy load. The load is generally limited to about one-half the rated capacity for any given duty cycle.

EQUIPMENT

For manual welding of thin materials, either for ac or dc, there are several types of Heliweld holders designed for light-duty and heavy-duty work. For automatic welding there is the Heliweld Head. The latest model will provide aproximately 30 ipm on vertical welding. This is particularly desirable when welding the lighter gage materials.

The advantages of this model include high sensitivity; it can be used with either helium or argon and works well with dc, balanced ac or ac with continuous high frequency. Remote controls are now being designed for motor carriage delay, wire feed delay and speed controls for both. Control panels and control stations are available to provide means for controlling gas and water flows, welding current controls, along with a water flow switch which provides protection to the water-cooled equipment.

High-frequency spark-gap oscillators are available for arc starting with d-c welding current. Figure 9 shows spark-gap oscillators in banks of three for starting three d-c arcs simultaneously.

Arc starters are available for arc starting or touch starting in place of high frequency by mechanical and electrical means. Figure 10 shows arc-starter for establishing the arc by the touch-start method. The electrode is set for a predetermined arc gap. By electric current through a solenoid the holder is held in position. To establish the arc the solenoid is de-energized, the holder is released, bringing the electrode in contact with the workpiece. When this is done, another voltage is established which in turn re-energizes the solenoid bringing the holder to the predetermined setting and at the same time, establishing the arc.

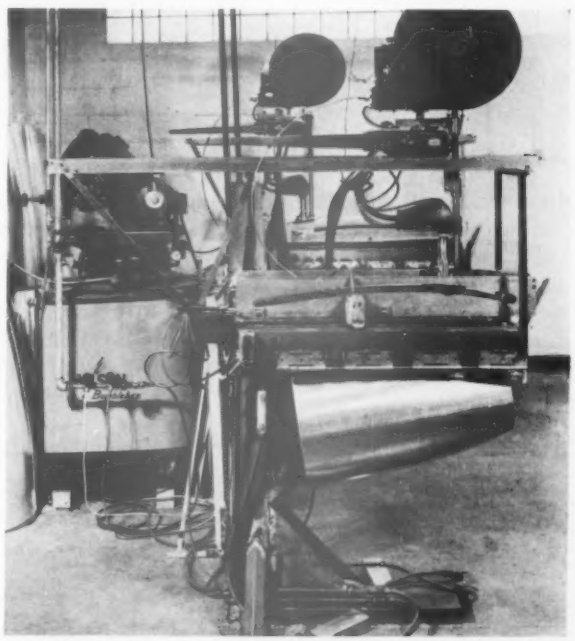


Fig. 11 Side view of dual Heliweld setup

The wire feed is a device for supplying filler metal to the weld when required. It has a variable speed motor which permits the various speeds of filler wire feeding where necessary. Figure 11 shows a side view of a dual Heliweld setup with wire feeding accessories.

The ability of the Heliweld Head to maintain a predetermined arc voltage is extremely important in producing uniformity of the bead width, depth of penetration, avoidance of distortion with the process.

The tungsten electrode is in a fixed position relative to the welding holder and gas nozzle. Arc voltage is maintained and corrected if any fluctuations occur due to contour change. This correction is acquired by two electric motors, controlled by an electronic circuit, one

motor for up and one for down. When the arc voltage exceeds the predetermined voltage setting in one direction or the other, the voltage control signals the motors until the voltage equals the preset arc voltage.

CONCLUSION

In general, the foregoing comments suggest the length to which welding engineers have gone on the inert-gas tungsten-arc process alone in the development of equipment and procedures to meet the problems and solve the needs relating to the effective and economical welding of thin-gage materials on a production basis.

PRACTICAL WELDER AND DESIGNER

Heliarc Welding Puts the Freeze on Cost

HELIARC welding is being used for the first time in manufacturing evaporator units for refrigerators. One of the final operations in fabricating the evaporators consists of welding a back plate to the drawer-shaped unit. Heliarc welding offers two advantages in this application; it provides the high-quality welds needed, and it substantially reduces production time requirements.

Two units of $^3/_{32}$-in. deep drawn 1010 steel are clamped in a rotating jig; one upright, the other upside down. In the fabricating process every evaporator unit requires seven skip welds, each $^3/_4$ in. long. When the welds are completed on one evaporator, a twirl of the jig brings the second unit in position for welding with no loss of time. Each skip weld takes 10 sec, and in less than $2^1/_2$ min two units with a total of 14 welds are completed.

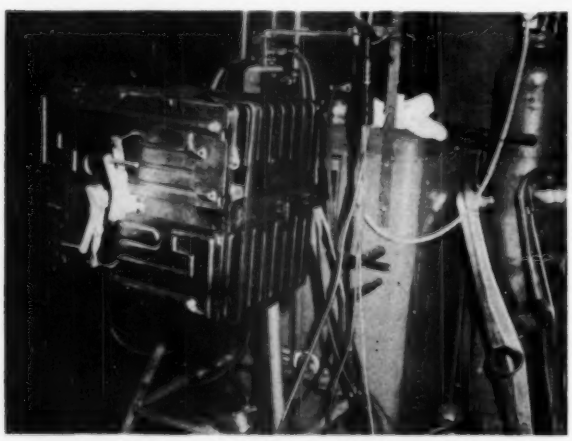
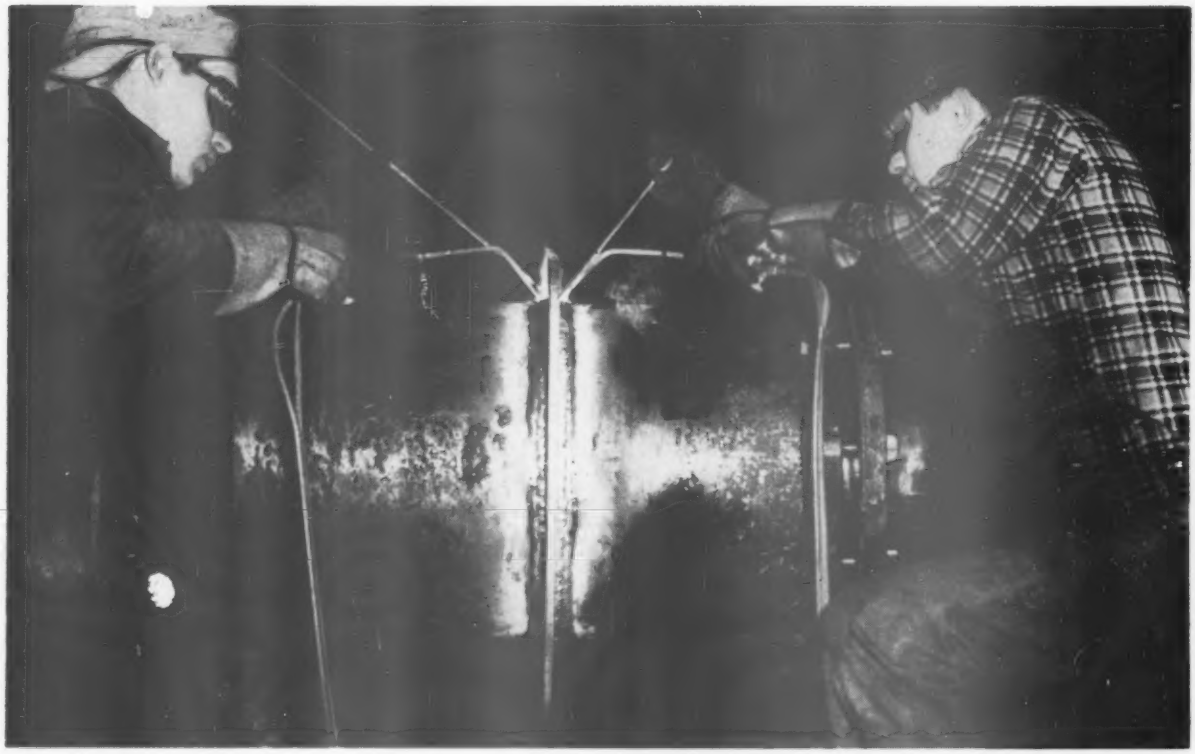


Fig. 1 Two units are clamped in this rotating jig, one upright, the other upside down. This facilitates speed of handling, and since each skip-weld takes only 10 sec to complete, the entire production is efficient and economical

Fig. 2 A Heliarc HW-10 torch in operation on one of two jigged units. A half-turn of the jig will bring the second unit in position for welding, and in less than $2^1/_2$ min, both units will be finished

These spatter-free welds require no mechanical finishing, and upon completion all units need only to be degreased, zinc plated and they are ready for installation.



Braze Welds Join Cast-Iron Conduit

Oxy-acetylene flame processes used in producing underground piping

by P. B. Foster

CAST-IRON pipe has been in constant use in the famous gardens of Versailles, France, since the year 1684 and is still in good repair. Oxy-acetylene braze welded cast-iron pipe conduit promises to produce similar records of long, leakproof service.

Braze welding was selected as the joining process in the fabrication of cast-iron pipe conduit for underground steam and water lines because the bronze weld metal is highly resistant to corrosion, an important factor in underground installations. Since braze welds have about the same resistance to corrosion as cast iron, this pipe conduit has no weak points that will need costly and inconvenient repairs.

Each section of conduit consists of a large diameter pipe which serves as the outer shell, internal pipes to carry the steam, water or other liquids or gases, and circular braces that hold the internal pipes in place inside the outer shell. These braces fit across the inside

Fig. 1 This welding team is tack welding an anchor plate in position on a section of cast-iron pipe conduit. A 12-in. steam line runs inside the conduit. Other conduits enclose steam, water and oil pipes

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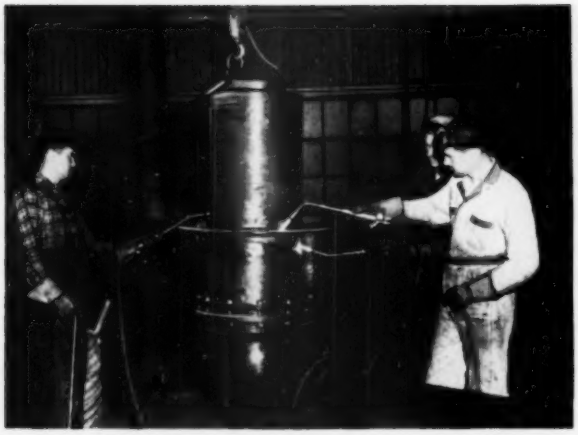


Fig. 2 After the anchor plate has been tack welded in place, the area around the weld zone for a distance of 4 to 5 in. back of the weld, is preheated to prevent cracking

Fig. 3 Both welds are started at the bottom and progress at the same speed to the top of the conduit. Then the welding operators move to the other side of the conduit and repeat the welding operation

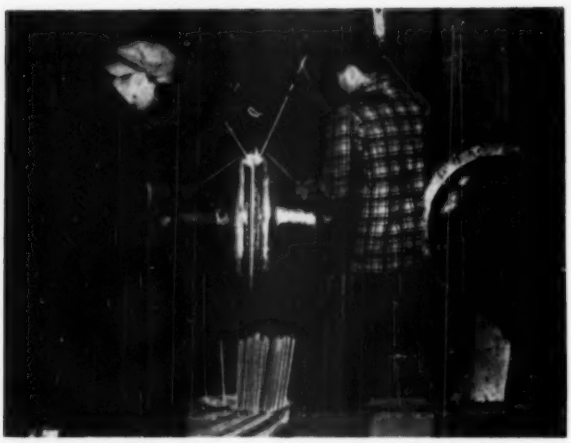


Fig. 4 Here the welding operators are finishing the welds that join the anchor plate to the conduit shell. Welding skill and teamwork produce two welds, one on each side of the plate, of equal strength and appearance

Fig. 5 This cutting operator is using a section of galvanized pipe as a support while he cuts bolt holes in an anchor plate. Other anchor plates, marked for cutting, are stacked at right

of the outer shell and are braze welded in position. The steam or water pipes pass through holes cut to size in these bracing disks.

The longest braze welds made on this pipe conduit join the anchor plates to the outer shell. Anchor plates are needed wherever the conduit can be secured to masonry or other permanent underground fixture. Anchor plates are much larger than the circular braces and are square with rounded corners and have a bolt hole in each corner. These plates centralize the inner pipe and have the outer pipe butting up to them so that a fillet weld must be made on each side. Conduit sections are aligned in vertical position.

WELDING PROCEDURE

All edges to be braze welded are ground free of all rust, dirt or scale. Two braze welds are made to join the anchor plates to the outer shell, one on either side of the plate. Both welds are made simultaneously so that heat from a welding blowpipe does not burn out an already completed weld. Ingenuity is combined with welding skill in braze welding these plates to the conduit. Two welding operators, one right-handed and the other left-handed, team up to do the job. Both welders make a circumferential weld, one on either side of the anchor plate, while working in their most comfortable position. Teamwork is important in this job since both welders must work at the same speed, keeping opposite each other for the entire welding operation.

Tack welds hold the anchor plates in place while preheating and braze welding is being done. The conduit section is supported in a vertical position while the tack-welds are being made. Then the entire area around the weld zone is preheated with large heating blowpipes until the metal reaches a temperature of from 300 to 400° F. When the correct preheat temperature has been reached, the conduit is lowered to a horizontal position and the circumferential braze welds are made joining the anchor plates to the outer shell. In this position, it is easier to make both welds of the same size.

To assure good quality welds, free from impurities,

Fig. 6 Fusion welding is used to join sections of galvanized iron pipe conduit. The area between welds on this section has been wrapped with asphalt-treated felt paper for greater resistance to corrosion

flux-coated bronze welding rod is used. The flux coating enables the welding operators to concentrate on control and movement of the weld puddle without thinking of adding flux or reaching for the flux can. When the welds are completed, the weld area is wrapped in fiber glass insulation and allowed to cool slowly for about ten hours.

FLAME CUTTING USED

Oxy-acetylene flame cutting is used to cut all pipe lengths to size and to bevel the pipe edges. Anchor plates and circular braces also are formed and bolt holes are cut using oxy-acetylene cutting blowpipes.

Some pipe conduit is fabricated from galvanized iron. Oxy-acetylene fusion welding, using a mild steel welding rod, is the joining method used on galvanized pipe. Asphalt treated felt paper is wrapped around galvanized pipe conduit after it has been fabricated to increase its resistance to corrosion.

From Welding Operators to Home Decorators

by Joseph Burval

MANY designers of modern furniture have turned to "wrought iron" for those qualities of strength, appear ance and simplicity typical of modern design. Almost overnight, leading stores are bursting at the seams with tables, chairs, lamps, ash trays and ornaments of every description, all made of wrought iron.

Many of these wrought iron articles are welded to shape with oxy-acetylene blowpipes in the hands of operators skilled in forming decorative iron products who never thought that they would be in the furniture business. Experience along this line has made one ornamental iron shop a sought-after manufacturer of wrought iron creations. Increased demand for its products has prompted the company to gear a sizable part of its production to welding ash trays and lamp stands of wrought iron.

All that is needed to fabricate these items is $^1/_4$-in. iron rod, a blowpipe, oxygen, acetylene and welding rod. This company went a bit further and designed its own jigs for easy welding on a mass production basis. One of the very popular products is a four-legged ash tray which can be altered into a variety of styles. Two lengths of wrought iron rod are cold-bent into a 2-legged shape, standing $2^1/_2$ ft high. Similarly, the ends of two 4-in. long rods are bent at a 45-deg angle, to serve as cross braces. They are positioned in a jig and welded as shown in Fig. 1. No finishing is necessary except for a coat of black paint. These stands are made for a pottery manufacturer, who finishes them off with unique ash trays of the company's own design.

Another wrought iron item in demand is designed to serve as a lamp base. A round, 16-gage iron plate, ranging in size from $3^1/_2$ to $7^1/_2$ in. in diameter has five U-shaped rods welded to it in a jig as shown in Fig. 3. These rods act as legs and will support the lamp 3 in. above a table top. Two holes are drilled into the plate

Fig. 1 Wrought iron ash tray stand positioned in a jig for easy oxy-acetylene welding

Joseph Burval is with the J. B. Ornamental Iron Co.

Photos courtesy of J. B. Ornamental Iron Co. and Haeger Pottery Co.

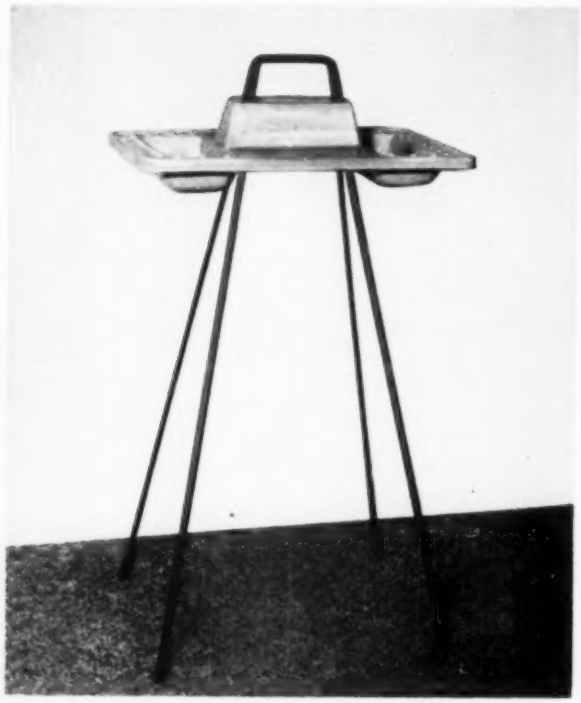


Fig. 2 Rubber tips are attached to the painted stand. A ceramic ash tray completes this attractive piece of furniture

Fig. 3 A wrought iron stand for a table lamp positioned in a jig for oxy-acetylene welding

for the lamp bolt and light switch. These stands are attached to tall, cylindrical, shade-type lamps which would add a gay decorative touch to any home.

For this product, many variations in style are required. They are made simply by changing the jigs. The basic equipment is the same for every stand.

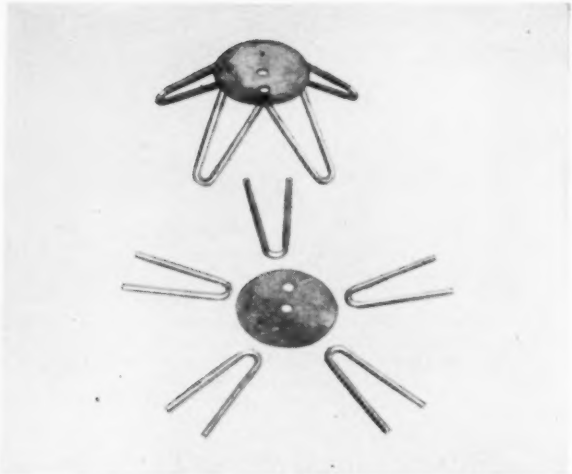


Fig. 4 A view of the welded lamp stand and the parts which make up the stand before welding

Fig. 5 The lamp stand is finished off with a bulb socket and a decorative shade

Jet Rings

JET engines are wedded to rings. From nose cowl to exit nozzle, these powe. plants are circular, sheet metal affairs strung together with bands of stainless steel. The gleaming rings bolt combustion chambers, turbine cases, exhaust cones, tailpipes, afterburners and case weldments together. They also serve as housings for bearings and structural bands to reinforce assemblies.

To feed jet engine production lines, Ryan Aeronautical Co., San Diego, Calif., buys thousands of rings at a time. Running from 5 to 42 in. in diameter, these stainless steel components cost almost a million dollars a year. Some of them weigh as much as 350 lb each. They are precision-machined and welded to jet engine assemblies.

Called upon to sustain severe structural loads and intense temperatures, the rings must be tops in quality. Their cost is commensurately high. But, through concentrated application and excellent development work on the part of suppliers, these costs have been substantially reduced. Improved fabrication techniques are saving the company thousands of dollars a month.

Rings are purchased from American Welding and Manufacturing Co., Dresser Industries, Inc., and Taylor Pipe and Forge Co. One of the largest flash-welded, stainless steel rings known, having a cross-sectional area of 11.7 sq in., is being produced to meet Ryan needs.

Because the rings which go into jet engine structures form mating surfaces, they must be machined to exact dimensions. Most are flange-type rings, with "L"-shaped cross section, They are machined to ±0.005 in. OD and ID and 63 microinch surface finish.

There are a number of ways to purchase stock for these rings. But, the costs vary greatly and that is where Outside Production performs a valuable function. They can be bought as cast sleeves and machined to size. They may be purchased as forged sleeves. Or, rolled bars may be flash welded into rings and used. Between 90 and 95% of the rings procured are of the flash-butt-welded type.

FORGINGS

Forged rings, or sleeves, possess good structural properties because the metal is refined by the blows of the forging hammer. These rings are produced by flattening a hot, rectangular billet of stainless steel. A hole is then pierced in the center and the disk is laboriously flattened into a large ring, or sleeve.

Fig. 1 John Lepman, Ryan Buyer, displays a variety of the stainless steel rings which Ryan purchases in large quantities for use in building jet engine components

Because forging is not a precise method of forming, a goodly amount of excess metal is left on the sleeve to cover the final machined dimensions. This metal must be paid for before it is thrown away. Then, extra machining costs must be incurred in order to remove this excess metal to get the finished ring. Forged rings are relatively expensive because their production involves the use of substantial amounts of labor and equipment. Ryan uses forgings when procurement time is limited because they are readily available.

CASTINGS

When cast rings are purchased, excess metal is also a factor which accounts for added weight and extra machining costs. Although castings may run 30% less expensive than forgings, they do not possess as good physical properties because of their grain structure. Also, castings may contain imperfections, such as porosity or occulsions, which render them useless. These defects, not detectable by X-ray, may remain hidden until expensive machining operations uncover them.

With both forged and cast sleeves, Ryan removes more metal by machining than is left in the finished ring. Since these rings are purchased on a weight basis, more than half of the costs of these rings is for scrap. Another cost, creeping into this picture, is the added transportation charges required to ship this excess metal.

In order to keep these costs down, forgings and castings are obtained in the form of sleeves from which a number of rings may be machined. After machin-

Fig. 2 A dozen high-temperature alloy rings are used in Ryan-made aft frames, for General Electric J-47 jet engines, to hold combustion chambers and engine bearings

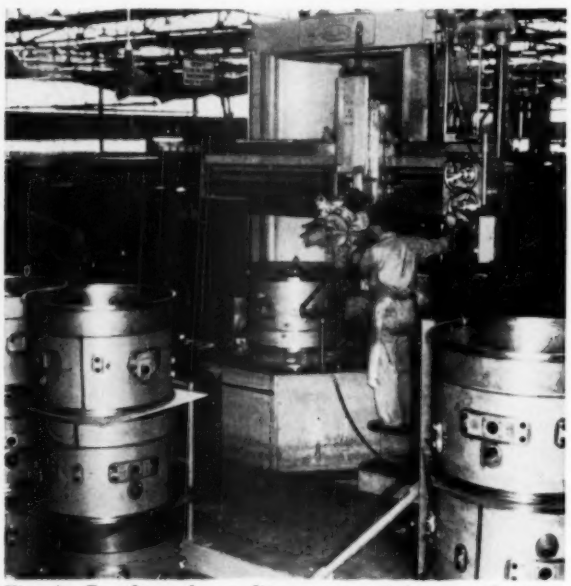


Fig. 3 Cut from large diameter, stainless steel rings, these flanges for after burner cones are machined in Bullard vertical turret lathes at Ryan. They must have 63 microinch finish with diameters which are within ±0.005 in.

ing, each ring is parted from the sleeve by the lathe's cutting tool.

FLASH WELDED

With the development of modern methods for flash butt welding large stainless steel sections, it is possible to obtain high quality rings at lower costs than forging or casting. American Welding and Manufacturing, Dresser Industries and Taylor Pipe and Forge perform this work. Rolled bar stock in precise thickness, width and length is obtained from steel mills. The following operations are then performed:

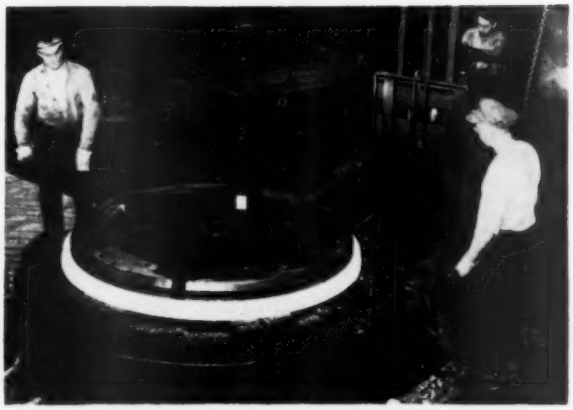


Fig. 4 Gleaming white-hot from the furnace, a flash-butt-welded ring is sized to exact dimensions on a powerful expanding mandrel at American Welding and Manufacturing Co.

Fig. 5 In a shower of scintillating sparks, Dresser Industries, Inc., flash butt welds a large stainless steel ring into a strong, continuous unit

1. The bars are cut to ring length and rolled into circular form. This is accomplished on either a bulldozer or a three-roll machine. Actually, the form obtained is a "D" shape.

2. The ring is placed in a flash-butt-welding machine and the ends are welded together. Flash welding is the only type of welding which will perform the joining of such heavy sections to the exacting requirements of jet engine fabrication.

3. Excess weld metal is removed by chip hammer. The ring is annealed in a furnace and squeezed into circular shape.

4. The hot ring is placed on an expanding mandrel and sized.

Made from rolled steel, flash-welded rings have good physical properties. They are approximately 45% cheaper than forged rings and 22% less expensive than castings. New flash-welding techniques are providing the means for making the very large rings, running up to 42-in. diam, which Ryan uses.

MILL SECTIONS

Development of sources for mill sections promises to pay sizable dividends. Savings, amounting to more than a hundred thousand dollars on recent programs, placed Ryan in an advantageous competitive position with substantial ultimate savings to customers and taxpayers.

Special rolls were purchased for use by the steel mills furnishing bar stock. With these rolls, bar stock having exact cross section are rolled. The lengths are delivered to the fabricators who flash weld the stock into rings. The rings are shipped to Ryan.

Now, we have a ring which almost conforms to the exact dimensions required by production. Only finish machining is required. Practically no excess metal has to be removed. Because these rings do not have large sections cut out by machining, they have better physical characteristics. The grain structure of the metal is oriented along the contours of the part.

Frequently, mill sections are rolled with a channel-type cross section. These are called "siamese" sections because two rings can be machined from each section. The rings are placed in vertical turret or gap lathes and rough-machined. Then, they are parted and finish-machined. This innovation saves machining time and provides a good means for holding one ring while the other is machined.

Rings made from mill sections cost only one-half as much as flash-welded rings from rectangular stock and one-fourth as much as forged rings. In addition, they require about half of the machining labor demanded by other rings.

As a result of Outside Production's development of mill sections, standardized methods of procurement, keyed to Ryan standards are being formulated by Production Engineering. Initial planning for new sales orders can then be developed to call for the ordering of rings by either forgings, flash-butt-welded rings or mill sections, whichever is most advantageous from a standpoint of schedule and cost.

EXTRUSIONS

Newest trick for making jet engine rings has been divulged by a French method, the Ugine Séjournet process. This is a practical method for producing solid and hollow sections of high-alloy steels through extrusion. The hot billet is impregnated with glass wool and pushed through a die. The fused glass film acts as a lubricant, preventing metal-to-metal contact between billet and die.

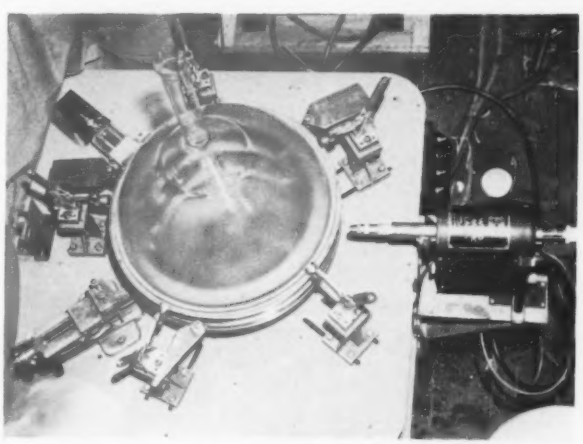
Extrusion takes between two and four seconds to produce sections running up to 40 ft long. Because of the low cost of the dies, compared with steel mill rolls, and the ease with which they can be put to use, this new process promises jet rings at lower costs. However, other factors, such as die life, must be taken into consideration to determine if a particular run can be produced more economically by this method. The process is capable of producing hollow sections which cannot be made by hot-rolling methods.

Inert-Gas-Shielded Arc Welding of Color TV Picture Tubes

by H. A. Huff, Jr.

RESEARCH engineers of Corning Glass Works, Corning, N. Y., one of the leading producers of all glass bulbs for picture tubes for the huge television industry, were faced with a peculiar problem, which was this: The internal parts necessary for compatible color TV picture tubes were too large to install through the thin, open end of the glass bulb. Corning came up with this solution: manufacture the bulb in two sections, firmly position the internal parts, the largest of which is the aperture mask, and weld the two glass sections together. But, the glass itself could not be sealed with heat as it might affect the sensitive parts inside. Metal bands of some kind would be required. The decision was to attach stainless steel flanges to the two glass sections and butt them together tightly in a special rotating fixture and then weld these parts together by moving the seam past a high-speed, automatic welding machine.

H. A. Huff, Jr., Welding Specialist, Air Reduction Sales Co.



Automatic inert-gas-shielded arc welding of TV color picture tubes as performed at Corning Glass Works, Corning, N. Y.

The right kind of welding process and equipment were of vital importance to a successful end result. Inert-gas tungsten-arc welding process employing a Heliweld Automatic Welding Head, was specified for the job.

The automatic head used, specifically designed for welding TV tubes, is an electronically controlled unit.

The sensitive servo-mechanism and automatically controlled arc voltage maintain a constant arc length, compensating for slight irregularities in the work. This guarantees consistent weld quality.

The head was mounted in the horizontal position for which a spring and strap assembly is supplied. A non-consumable thoriated tungsten electrode, 0.040 in. in diameter, was used. The inert gas, argon, (helium or a mixture of argon and helium may be used) completely shielded the work from atmospheric contamination. The welding speed was 50 ipm on the 19-in. circular tube steel flanges.

Pipe Welding

WELDERS at TEMCO Aircraft Corp. are using a unique V-block device to lay out reference points on horizontal pipe they cut and assemble in jig-building.

The V-block virtually guarantees accuracy on layout preparations for halving, quartering or attaching metal pads to pipe of any diameter. In addition, the block saves layout time at the Dallas, Tex., plant—about $^3/_4$ man-hour per shift on the average.

Welders had found it difficult to hold accuracy when making lengthwise cuts on long pieces of pipe. They could establish a centerline mark on one end of the pipe. But when they tried to mark a similar point at the pipe's other end, they had no means to insure that the two points, connected, would provide a straight line.

Welder Charles Gonday, of 9007 Diceman Drive, Dallas, found the answer at a cost of only $5.00.

Basically, the tool he designed is an aluminum V-block, $4^1/_2$ in. wide. A 10-cent protractor is mounted on a plate attached at one end of the V-block. A movable metal pointer is fixed so that it sweeps across the face of the protractor, and a $2^1/_2$-in. bubble is mounted so that it moves with the pointer.

A prick punch is inserted at the point of the V—in line with the 90-deg point on the protractor.

To establish a centerline on horizontal pipe, Gonday places his V-block on one end of the pipe, sets the pointer at 90 deg on the protractor, and adjusts the block until the bubble is centered. Then he taps the punch, which marks on the pipe one end of the centerline.

He repeats this operation at the other end of the pipe, then connects the points with a straightedge, if the pipe is short, or by popping a line, if the pipe is long.

If he wants to cut out a quarter-section of the pipe, lengthwise, he uses the line he has just drawn as one guide line. To get the other, he moves the pointer on his V-block to 0 or 180 deg on the protractor. Then he slides the block around the curve of the pipe until the bubble again is centered, and taps the punch again.

This procedure—repeated at the other end of the pipe—provides the two terminal points for the second guide line. The lines are exactly 90 deg, or one-quarter of the pipe's circumference, apart. The same procedure is used to halve or otherwise section pipe lengthwise.

Layout problems that normally complicate pipe cutting are solved by this ingenious V-block. Equipped with a protractor, leveling bubble and prick punch, the block enables its user to lay out any precision reference point on horizontal pipe. Designer Charles Gonday, above, is preparing to mark a point some 17 deg off the centerline

Another chore that Gonday's V-block simplifies is that of accurately positioning pads on jigs made of pipe. These flat metal pieces are used to position or support assemblies that will be built in the jigs. Often, they must be attached at a precise number of degrees from horizontal.

Gonday can locate attach points for pads simply by centering his V-block bubble with the pointer registering the required number of degrees off the centerline. A stroke on the punch marks the spot where the pad should rest.

the AMERICAN WELDING SOCIETY

activities • related events

American Welding Society Plans National Fall Meeting

Nineteen sessions covering all phases of welding activities will feature the AMERICAN WELDING SOCIETY National Fall Meeting to be held in Chicago, Nov. 1 to 5. Fifteen hundred welding and production engineers, technical management men and others interested in welding are expected to attend these sessions where fifty-seven papers will be presented.

Among the subjects to be discussed are the welding of titanium, aluminum and molybdenum, the use of welding in the production of aircraft and rockets, welding high temperature materials, inert-gas-shielded arc welding, resistance welding, and fused metallized coatings. All sessions will be held at the Sherman Hotel.

A highlight of the meeting will be the Adams Lecture on Monday morning, to be presented by William L. Warner of Watertown Arsenal. His paper will be on "The Toughness of Weldability." At this same session a number of other honors will be presented to individuals for outstanding contributions to the advance of welding.

The AWS Annual Fall Meeting will run concurrently with the National Metals Exposition at which welding and cutting exhibits and demonstrations will be shown. The Exposition will be held in the International Amphitheater.

American Welding Society District No. 6 Meeting Denver, Colo.

The last annual meeting of District No. 6 was held at the Shirley-Savoy Hotel, Denver, Colo., June 11 and 12, 1954. The following were present.

Houston—P. V. Pennybacker, Joe Hoffman, James Earthman, H. H. Wehner and W. H. Greer.

Tulsa—F. D. Davenport and James B. Davis.

St. Louis—Neil Stueck and George O. Bland.

Dallas—Wayne A. Thompson.

Wichita—Ray L. Townsend, William E. Bush and Roy Whitt.

Kansas City—E. R. Wyckoff, F. G. Singleton and A. G. Hedstrom.

Des Moines—George C. Sullivan.

Denver—H. Jackson, D. C. Car, Herman Geller, C. Brinton Swift, J. L. Fry and William S. Smith.

Seated, left to right, Ray L. Townsend, Joe Magrath and C. Brinton Swift. Standing in background J. E. Dato and F. D. Davenport

Albuquerque—Willis G. Groth.

New York City—J. G. Magrath, National Sec'y. A.W.S. and J. E. Dato, District Director.

After breakfast and a general round of renewing acquaintances, the National Reorganization of the AWS Districts was discussed. The nominees for District Director were called on and each had appropriate remarks regarding the future. Being the last meeting of District No. 6, it was unanimously agreed to hold a joint meeting of Districts Nos. 8 and 9 for 1955 in Kansas City.

A general report was made by each section represented. These reports covered meeting attendance and general ideas to make meetings a success. Here are some of them, how many have you tried?

1. Member and non-member name badges.
2. "Keg" or "social hour" preceding the meeting.
3. Non-technical film while the "gang accumulates" (These are available from large companies and government agencies, both federal and state).
4. Coffee speakers (F.B.I., Treasurer, Fire, Sports, Bank, Law, etc.).
5. At least one non-technical meeting a year (including the fairer sex is always a good idea).

District No. 6 Meeting

6. Get good speakers.
   (*a*) Section cooperation on speaker circuits.
   (*b*) Inform speaker on type and size of group.
   (*c*) Arrange for good equipment and competent operators for slides and movie projection.
   (*d*) Make him feel welcome by handling reservations and some limited entertainment if he is a "stranger" in the area.
   (*e*) Give him and his company some good publicity (newspaper, WELDING JOURNAL, meeting announcement, letter of appreciation, etc.).
7. Technical Secretary Reports.
8. Membership Committee Reports.
9. Awards for getting members (AWS pin).
10. Form sub-divisions of section in outlying areas.
11. Well-balanced section organization between "user" and "sales" members.
12. Regular meeting dates and place are a must.
13. Plant tours and demonstrations.
14. Welding Symposiums (preferably not too technical and aimed at stirring interest among college students).
15. Selected mailing lists for special meetings.
16. Joint meetings with other Societies.

J. G. Magrath talked informally on the Society and gave some of the details of the forthcoming National Welding Show to be held in Kansas City June 7, 8, 9 and 10, 1955. He also gave statistical data regarding the last two shows at Houston and Buffalo.

Speaker circuits were worked out between the sections and business was concluded with a social hour.

The following day a wonderful social outing was enjoyed by all. This included a trip to the mountains, entertainment and dinner. The group photograph taken at mid-point of the activities indicates a happy time by all and everyone seems to say "See you in Kansas City in 1955."

J. E. Dato

Board of Directors' Actions

Some of the Actions were previously reported in the August issue of THE WELDING JOURNAL.

This meeting was held in Parlor B, Mezzanine Floor, Hotel Statler, Buffalo, N. Y., on Thursday, May 6, 1954, at 10:00 A.M., with the following in attendance.

Members: F. L. Plummer, *Chairman;* J. H. Humberstone, C. A. Adams, J. H. Blankenbuehler, J. J. Chyle, J. E. Dato, D. B. Howard, C. E. Jackson, C. F. Jennings, J. W. Mortimer, I. Morrison, I. A. Oehler, A. E. Pearson, H. W. Pierce, C. P. Sander and R. L. Townsend.

Staff: J. G. Magrath, *Secretary,* and F. J. Mooney, *Assistant Secretary.*

Guests: R. D. Campbell, 2nd Vice-Chairman, Niagara Frontier Section; H. M. Priest, Chairman, Special Committee on Awards; R. Siemer, Secretary-Treasurer, Niagara Frontier Section; G. V. Slottman, Chairman, Special Committee on Membership Classification; and J. R. Stitt, Chairman, 1953–54 National Membership Committee.

Call to Order:

(*a*) *Greetings:* Chairman Fred L. Plummer read a telegram received from Miss M. M. Kelly, Secretary Emeritus, wishing the SOCIETY success at its Second Spring Meeting and Welding Show. Appreciation was voiced by the Board Members for these thoughtful greetings.

(*b*) *Approval and Acceptance of Minutes:* (1) The minutes of the First Meeting of the Executive Committee for the 1953–54 Year, held in New York on Tuesday, Mar. 23, 1954, were approved by the attending Members of the Executive Committee, but subject to the correction of inclusion of the name of J. H. Blankenbuehler as an Attendee. Mr. Blankenbuehler's name was unintentionally omitted from the minutes as issued.

1. Membership Committee Appointment

The Secretary advised that in the order of the revisions to the By-Laws whereby the term of the Chairman of the National Membership Committee extends from May 1st through April 30th, the term of J. R. Stitt, Chairman of the National

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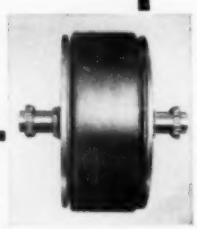

Overloading or accidentally dropping the load on an Aronson Turning Roll WILL NOT crush and ruin the tire. The Overload Disc of steel placed on each side of each tire is smaller than the tire by just that amount which allows a safe deformation (flattening) of the tire which occurs at maximum load. Compression and tension Tie-Rods hold the Overload Discs firmly against the steel rim of the rubber tire, forming an effective axle as large in diameter as the O.D. of the steel tire rim. Crushing the tire is impossible regardless of the load put on an Aronson Turning Roll. Large Timken Bearings maintain perfect alignment.

Any Tank or Cylinder will be somewhat out-of-round and will not be straight, but will have a belly or bend in its average centerline axis. In the case of non-rigid cylinders, multiple rolls are used to hold a true centerline, ironing out the belly or bend. When working rigid tanks and cylinders, it is best to have one roll at each end so as to avoid the belly placing all the load on the middle roll when that belly is down, and all the load on the two end rolls when the belly is up. It is to allow for the average amount of out-of-round and belly in cylindrical workpieces that ARONSON has stressed all units for 100% overload Protection. Momentary overloads as high as 100% will not breakdown an Aronson Roll.

AVOID DAMAGE LIKE THIS

UNDERCUTTING CAUSED BY OVERLOADS

Continuous overloads on this tire caused the rubber to bulge out over the steel band. This, in turn, set up a shearing or cutting action in the tread. Tire is ripped around the bond on both sides and is about ready to fall off.

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Miller Heavy-Duty Industrial A.C. Arc Welders

These transformer-type welders achieve high-quality welds at maximum production speeds, feature low maintenance and long life. Ample open circuit voltage stabilizes arc, minimizes "arc-out" time, permits use of all A.C. or A.C.-D.C. electrodes. Continuous current control. Models 102, 103, 104, 105 and 106 rated at 200, 300, 400, 500 and 600 amperes respectively (60% duty cycle at 40 volts). Power factor correction at slight additional cost. Models 105-SA, 107-SA, 108-SA and 109-SA are specifically designed for submerged arc welding, have selective open circuit voltages for automatic welding. Rated secondary amperes (60% duty cycle at 40 volts) are 500, 750, 1000 and 1500 respectively. All SA models are power factor corrected.

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But the boss has even *more* reasons for specifying Nickel-Arc. *Better machinability*, the result of the special core wire and coating of Nickel-Arc, cuts his machining cost, improves appearance. And the *confidence* of his welders in the finer performance of Nickel-Arc electrodes guarantees better workmanship on their part.

Standardize on Nickel-Arc, the electrode that is best for machineable welds in cast iron. Order Nickel-Arc from your nearby Alloy Rods Distributor or write the plant for information.

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Membership Committee 1953–54 Year, had now expired. President Fred L. Plummer recommended the appointment of J. E. Dato to the Chairmanship of the National Membership Committee for a one-year term, May 1, 1954 to Apr. 30, 1955.

Action: Upon motion, duly seconded, the Chairman's recommendation was approved.

2. North Central Ohio Section

A group of Members in North Central Ohio, having met with the requirements for the establishment of an AWS Section, requested formal authorization to operate as the North Central Ohio AWS Section, with Headquarters located in Marion, Ohio.

Action: Upon motion, duly seconded, upon the Chairman's recommendation, the formation of the North Central Ohio Section was approved.

3. Fox Valley Section

A group of Members, having met with the requirements for the establishment of an AWS Section, requested formal authorization to operate as the Fox Valley Section, with Headquarters at Appleton, Wis.

Action: Upon motion, duly seconded, upon recommendation of the Chairman, the formation of the Fox Valley AWS Section was approved.

4. AWS Representation

AWS President Plummer was invited to appoint an AWS official Delegate to attend the Annual Meeting of the American Society for Engineering Education to be held at the University of Illinois, Urbana, Ill., June 14–18, 1954, which will commemorate the 50th Anniversary of the founding of the Engineering Experiment Stations in engineering colleges. Mr. Plummer recommended the appointment of J. Heuschkel, Chairman of the AWS Educational Committee as AWS Delegate.

Action: Upon motion, duly seconded, the Chairman's recommendation was approved.

5. Manufacturers Committee Appointments

(*a*) National Cylinder Gas Co., Chicago, Ill., have requested that K. F. Schattel, alternate Member for their J. L. Adank, on the AWS Manufacturers Committee, be replaced by N. S. Strandwitz, Assistant Sales Manager of that company as official alternate for J. L. Adank, Member of the AWS Manufacturers Committee.

Action: Upon motion, duly seconded, as recommended by the Chairman, the appointment of Mr. Strandwitz, replacing Mr. Schattel, was approved.

(*b*) In view of the retirement of H. R. Salisbury, representing the Air Reduction Sales Co. on the AWS Manufacturers Committee, and presently Chairman of

that Committee, the Air Reduction Sales Co. recommends the appointment of John L. Lincoln, Jr., Vice-President of Air Reduction Sales Co. to Membership on the AWS Manufacturers Committee.

Action: Upon motion, duly seconded, upon the Chairman's recommendation as well as that of the Air Reduction Sales Co., John J. Lincoln, Jr.'s appointment was approved.

6. Assistant Journal Editor

B. E. Rossi, Assistant Journal Editor, currently devotes one-fifth of his time to this office. Contemplated improvements in THE WELDING JOURNAL, starting with the January 1955 issue, will require several months' advance activity work. It has been recommended by THE WELDING JOURNAL Committee and Editor that during the months of August and September 1954, Mr. Rossi devote one-half of his time to the Office of Assistant Journal Editor (the Board of Directors previously approved Mr. Rossi's joining the SOCIETY on a full-time basis, starting Oct. 1, 1954). The SOCIETY's Secretary recommended that the recommendation of the JOURNAL Editor and Committee be approved.

Action: Upon motion, duly seconded, it was approved that Mr. Rossi be engaged during months of August and September 1954, on a half-time basis.

7. Report of Special Committee on Technical Services

The report of the Special Committee on Technical Services, as submitted by J. H. Humberstone, Chairman, was listed as Agenda Item G and was mailed on April 26th to all Board Members. J. H. Humberstone orally reviewed the important features of the report and recommended the establishment of a Standing Committee which would be known as the "Technical Council of the Board of Directors." H. W. Pierce emphasized the need for the Secretary's adding an item to the AWS National Officers and Management Manual which would call the National Nominating Committee's attention to the need for nominating a candidate each year whose experience and background would qualify him for serving on this Council on the basis of both technical and administrative ability. Mr. Pierce also observed the need for breaking down the functions of the Board of Directors through the means of, as much as possible, setting up a group of the present Standing Committees which are devoted to general policy activity in the category of the Administrative Committees. In discussion, it was agreed that the proposed Technical Council of the Board of Directors should be appointed as quickly as possible and that the extention of its supervision over the SOCIETY's Technical Activities, Educational Activities, Technical Papers Activities, Welders' Certification activities and other activities dealing with technical matters, should

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become effective at the beginning of the Society's new fiscal year—Sept. 1, 1954. Mr. Humberstone proposed that the "Objects of the American Welding Society" as outlined on page 2, of his Committee's report, should be adopted and be referred to the Constitution and By-Laws Committee for inclusion in the Society's Constitution in the order of approved legal text, the Constitution and By-Laws Committee collaborating with the newly appointed Technical Council on the wording thereof. He interpreted the pattern of operation of the Technical Council to include the approval of publication of new Codes, Standards and Specifications, stating that the Board of Directors, *et al.*, would thus be relieved of this activity but, nevertheless, have control by reason of the Technical Council consisting of membership representation from the Borad of Directors.

Action: Upon motion, duly seconded, the Board of Directors approved:

1. The Objects of the American Welding Society, as recommended on page 2 of the Committee's report.

2. The referral of those Objects to the Constitution and By-Laws Committee with the advice that the Board of Directors is in sympathy with the statement of Objects as submitted.

3. The establishment of the Technical Council of the Board of Directors and with membership to consist of pattern recommended in the Special Committee's report and designation of responsibility to the Technical Council of the Board of Directors for over-all supervision of the Society's Technical Activities, Education Activities, Technical Papers activities, Welders' Certification activities and other activities dealing with technical matters.

4. A vote of appreciation to the Special Committee on Technical Activities and approval of its discharge upon completion of its task, such to automatically take place at the time that it turns over its recommendations complete to the newly organized Technical Council of the Board of Directors.

5. Consideration of ASME Proposal

The Society's Secretary advised that the Executive Committee of the Metals Engineering Division of the American Society of Mechanical Engineers proposed that a joint meeting of their Division and AWS be held at the time of the AWS proposed 1956 Spring Meeting as, in the opinion of their committee, such conference would be of great technical value because members of their Division interested in welding could meet with our Members for the purpose of discussing welding from each other's viewpoints; each benefiting. He advised that the Executive Committee had approved of the proposal on the basis that the ASME Division would be responsible for arranging its own speaker program and would share in the operation costs of the meeting in proportion to attendance. However, in discussing the proposal with the AWS Technical Papers Committee, that Committee was somewhat concerned about the mechanics and coordinating activities. Since that time, W. L. Fleischmann, Chairman of the Metals Engineering Division of ASME, has met with B. E. Rossi, Secretary of the Technical Papers Committee of AWS, and it is believed that a satisfactory program of operation can be developed. However, the Secretary wished to know the thinking of the Board of Directors in regard to joining in meeting with other vertical societies or other divisions at the time of the National Meeting of AWS before he presents the proposal to the AWS Convention Committee, which Committee will be responsible for making a decision subject to its understanding of the thinking of the Board of Directors.

It was the unanimous thinking of the Board of Directors, at this meeting, that we should be very happy to accept the proposal of the Metals Engineering Division of ASME, if the pattern of activity can be coordinated and that we would certainly welcome them in joining with us in an activity of this type of interest to the membership of their Division and our Members.

6. Honorary Membership for H. O. Hill

The Honorary Membership and Honorary Directorship Committee, C. R. Jennings, Chairman, advised that his Committee proposes H. O. Hill for Honorary Membership in 1954.

Action: Upon motion, duly seconded, the Committee's foregoing recommendation received unanimous approval of the attending Board Members.

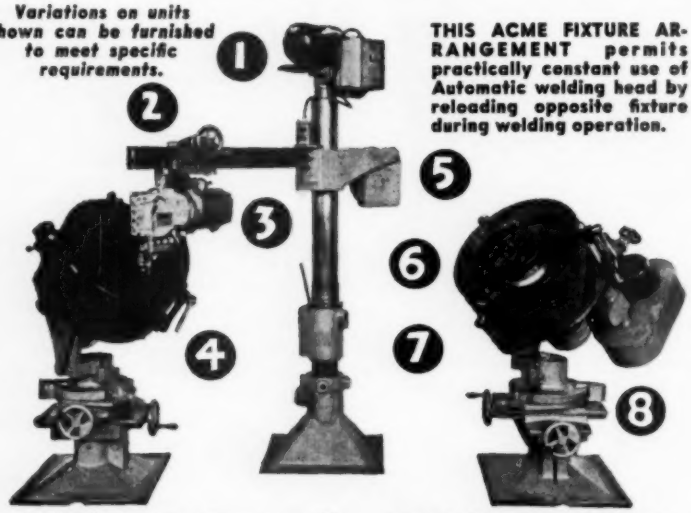
7. Civil Engineers National Congress Representation

Associate Professor A. A. Toprac, Department of Civil Engineering, University of Texas, AWS Member, is scheduled to give a Paper on welded structures at the 2nd International Congress of Civil Engineers at Caracas, Venezuela, Nov. 19 to 30, 1954, and he has offered to act as official representive of AWS at that activity. The Society's Secretary recommended acceptance of his request without obligation of expense to the Society.

ACME *Automatic* WELDING POSITIONER and FIXTURES

Variations on units shown can be furnished to meet specific requirements.

THIS ACME FIXTURE ARRANGEMENT permits practically constant use of Automatic welding head by reloading opposite fixture during welding operation.



1. Vertical power traverse with up and down inching button.
2. Hand wheel on carriage with locking arrangement for setting automatic welding head in proper relation to work.
3. Positioner arm swings and can be locked in proper position to either fixture.
4. 22" diameter wheel shown on fixture.
5. Fixture equipped with Reeves variable speed for proper feet per minute with reversing control. Fixture with two set speeds can also be furnished.
6. Holding machine can be set in either vertical or horizontal position. Shown in 45° angle.
7. Cross slide adjustment for fine setting so welding head on arm can be placed at either fixture without further adjustment.
8. Heavy copper brushes and holders mounted directly back of fixture for ground.

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Action: Upon motion, duly seconded, the Board approved the designation of Prof. A. A. Toprac in the capacity recommended.

8. Oklahoma City University Student Chapter

A group of students of the Oklahoma City University have met with all requirements and have submitted application for the establishment of a Student Chapter to be known as "The Oklahoma City University Student Chapter."

Action: Upon motion, duly seconded, the Board approved the organization of the Oklahoma City University Student Chapter.

9. Welding Clinics

The SOCIETY's Secretary advised that increasingly requests are being received from Sections to engage in, participate in or sponsor Welding Clinics in their area. He stated that inasmuch as a Section is part of the AMERICAN WELDING SOCIETY which is incorporated, should accident occur, the National SOCIETY might be liable for damages; therefore, it becomes necessary that if the Section directly sponsors such activity, then they should be covered with liability insurance. He cited the most recent case whereupon the Sangamon Valley AWS Section desired to put on a Clinic to be known as the "AWS Sangamon Valley Section Welding Show" on June 12, 1954, such to be held on the premises of the Leader Iron Works, Inc., Decatur, Ill. He felt that such activities should be encouraged for the benefit of the SOCIETY and the industry, but that a statement of policy should be written, published in THE WELDING JOURNAL and provided to all Sections considering such activity. He felt that the matter should also be discussed with the Manufacturers Committee and the SOCIETY's attorney.

Action: Upon motion, duly seconded, the Secretary's recommendation was approved with the advice that he consult with the Manufacturers Committee as well as the SOCIETY's attorney for the preparation of a statement of policy to be provided to all Sections and to be published in THE WELDING JOURNAL.

In further discussion, several Board of Directors' Members expressed the opinion that in each case a request for participation in a Welding Clinic should be carefully screened by the Secretary and that the thinking of the Manufacturers should be fully considered. Care should be exercised that a Section did not sponsor an activity which was exclusive with one manufacturer or organization. There was a strong feeling that it might be better if an AWS Section did not sponsor the Clinic, but rather leave the sponsorship to some other group and to extend its cooperation, participating to the extent of accepting space for Membership Promotion.

10. Adams' Lecturer 1955–56

The Committee on Awards, H. Malcolm Priest, Chairman, submitted the names of their two nominees, first and second choice, for the honor of giving the 1955–56 Adams' Lecture. In the order of SOCIETY By-Laws, a secret ballot was cast. La Motte Grover was unanimously appointed Adams' Lecturer for the 1955–56 year.

11. Resignation—J. B. Welch District No. 5 Director

As a result of advice received from his physician, J. B. Welch, District No. 5 Director, will be unable to continue a number of exacting activities. Among these will be the fulfillment of the duties of the Office of District No. 5 Director. Accordingly, Mr. Welch has regretfully submitted his resignation.

Action: Upon motion, duly seconded, the resignation of J. B. Welch was accepted, and the Secretary was instructed to advise Mr. Welch accordingly, with a statement of appreciation from the SOCIETY for the services he has so generously rendered.

Secretary's Note: In the order of By-Laws, the Secretary will advise the District that its District Executive Committee shall proceed to fill the vacancy created by the resignation of J. B. Welch, for the period of Mr. Welch's unexpired term.

12. Memorial Resolutions

(*a*) The SOCIETY's Secretary officially advised the Board of the death of Dr. W. Hess, Past President and Honorary Member of the SOCIETY.

Action: Upon motion, duly seconded, the Board voted that a Resolution Committee be appointed for preparation of appropriate memorial resolution for submission to Dr. Hess's family and friends.

Secretary's Note: On the order of the President, Prof. Robert A. Wyant and Frank W. Davis have been appointed as a Memorial Resolution Committee for Dr. W. Hess.

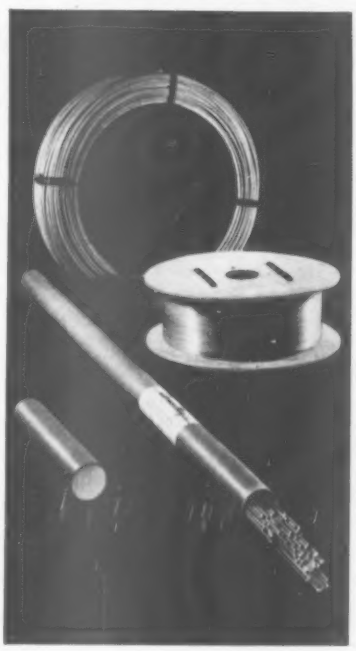
(*b*) The SOCIETY's Secretary officially advised the Board of the death of C. W. Obert.

Action: Upon motion, duly seconded, the Board voted that a Resolution Committee be appointed for preparation of appropriate memorial resolution for submission to Mr. Obert's family and friends.

Secretary's Note: On the order of the President, Dr. Harry C. Boardman and Herbert Reinhard have been appointed as a Memorial Resolution Committee for Dr. Obert.

(*c*) The SOCIETY's Secretary officially advised the Board of the death of G. E. Van Alstyne.

Action: Upon motion, duly seconded, the Board voted that a Resolution Committee be appointed for preparation of appropriate memorial resolution for submission to Mr. Van Alstyne's family and friends.



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QUALITY CONTROLLED
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Secretary's Note: On the order of the President, H. F. Henriques and T. C. Fetherston have been appointed as a Memorial Resolution Committee for Mr. Van Alstyne.

13. Membership Status Report

The Assistant Secretary orally reported that as of Apr. 1, 1954, the SOCIETY had a membership registration of 10,259, consisting of 9436 active and 823 delinquent members. As of the same date the SOCIETY had a registration of 211 Supporting Companies as compared to 195 at the commencement of the SOCIETY's membership year, Sept. 1, 1953. The 10,259 registration was compared against membership figures as of Sept. 1, 1953, at which time, the SOCIETY had a total registration of 9349 consisting of 9051 active and 298 delinquent members. The Assistant Secretary estimated that of the 823 delinquent members as of April 1st approximately one-half of these members were "Regular" September 1st Members, and if payment was not received prior to the close of April, their names would be removed from the membership rolls of the SOCIETY. On the basis of a one-month extention for delinquent members, there were 29 reclaimed during the month of April. He compared this figure to previous years which experienced an average reclamation of from 50 to 60 members during the one-month delinquency extension period.

14. Appreciation to Niagara Frontier Section

The Board of Directors extended a vote of sincere appreciation to the Niagara Frontier Section Arrangements Committee for the excellent work performed in bringing about the successful operation of the 2nd National Spring Meeting of the SOCIETY, held in Buffalo, May 4th through 7th.

Next Board of Directors Meeting

The next Meeting of the Board of Directors was tentatively set for Friday, Aug. 27, 1954, to convene at 10:00 A.M., in New York (probably the Hotel Statler). The Secretary advised that the August 27th Meeting of the Board of Directors will be the final meeting of the SOCIETY's fiscal year which terminates as of Aug. 31, 1954, and that such meeting will shortly follow a meeting of the SOCIETY's Finance Committee. Budget for the fiscal year 1954–55, based upon a ten-month operating report for the 1953–54 year, ending June 30, 1954, will be submitted.

Adjournment

The Third Meeting of the Board of Directors, 1953–54 was adjourned at 4:10 P.M.

Employment Service Bulletin

Position Vacant

V-312. Teaching position—Instructor or Assistant Professor. Require M.S. or Ph.D. degree in Electrical Engineering or Physics, with strong interest in teaching and research. Knowledge of the welding field is desirable but not essential. Courses to be handled include: welding theory and equipment, resistance welding and electronic controls. Minimum salary $4500 for nine months. Interested persons should forward completed résumé of educational and industrial experience.

Services Available

A-656. Recent graduate of technical school who has technicians certificate in welding and metallurgy desires position in service or production department. Particularly interested in training programs. Welding and sales' experience. Age 26, married, references.

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KEEN-ARC CARBONS

FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon arc graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

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Your choice of 51 electrodes	
TYPE	SELECTION
Mild Steel	9
Low Alloy Steel	4
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Stainless Steel	30
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☐ B-6070 Complete Line Electrodes
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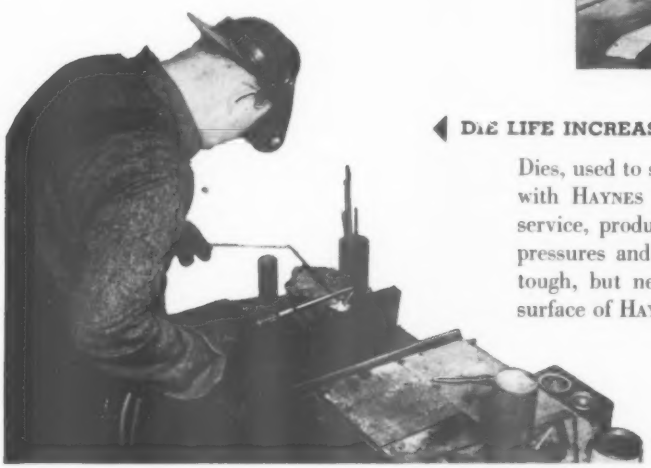
WJ-9-54

Hard-Facing Helped Here...it Can Help You Too!

LIFE INCREASED 400%

Hard-facing these entry guides with a wear- and heat-resistant HAYNES STELLITE alloy increases their service life from 4 to 5 times. Unprotected guides failed after handling only 40 tons of hot steel bars, while the ones protected with HAYNES STELLITE alloy handled up to 200 tons. The guides are subjected to continual abrasion and heat from the hot steel passing through them.



DIE LIFE INCREASED 500%

Dies, used to shape refractory tile, last 5 times longer when hard-faced with HAYNES STELLITE alloys. Hard-faced dies have given 10 years' service, producing up to 500,000 tiles. The dies have to resist high pressures and abrasion from dry press operations. Unfaced dies are tough, but need the wear-resistance gained from a hard, protective surface of HAYNES STELLITE alloys.

AN ALLOY FOR EVERY JOB

There are 14 different HAYNES hard-facing alloys. Some are hard and abrasion-resistant, some are tough and ductile, capable of withstanding the shock of severe impact; others give extraordinary service under conditions of corrosion, erosion, and heat. Descriptions of each alloy and procedures for applying it are included in the booklet, "HAYNES Alloys Hard-Facing Manual." Write today for your free copy.

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Hard-facing products made from cobalt-base alloys, nickel-base alloys, iron-base alloys, and cast tungsten carbide in the form of tube rods and coils.

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NEWS OF THE INDUSTRY

Letter to the Editor

Mr. C. A. McLean of Air Reduction Sales Co. presented an interesting paper at the 1954 Spring Meeting entitled "Inert-Gas-Shielded Tungsten-Arc Spot Welding." At the close of his presentation, someone asked for a suggestion as to how to shorten the name of this new process. I would like to suggest the following name: *Tig spot welding* indicating—tungsten inert gas spot welding.

The speaker was also questioned as to how to indicate such a spot weld on a drawing. It could be done simply by inserting as T in the standard spot welding symbol, thus:

The Welding Engineer
T. B. Jefferson, Editor.

Cornell and MIT Students Win Welding Awards

An article on "Underwater Metallic Arc Welding," by O. P. Eberlein and R. C. Waugh has been selected by the AMERICAN WELDING SOCIETY as the best student paper on welding to appear in an undergraduate publication during the year ending June 1, 1954. The authors of the paper will split a cash award of $200. *The Cornell Engineer*, who published the article in their May, 1954 issue, will also receive $200.

A second prize of $100 goes to Richard Hayes of Massachusetts Institute of Technology for his article "Recent Ship Failure Studies." The article appeared in the March 1954 issue of *Tech Engineering News*, and that student magazine will receive $100 for publishing the prize winning entry.

This annual award, directed by the AMERICAN WELDING SOCIETY, is sponsored by A. F. Davis, Vice-President and Secretary of the Lincoln Electric Co., Cleveland, Ohio, to encourage and stimulate interest in welding.

In addition to the cash awards which will be presented immediately, certificates will be awarded to the winners during the AWS Annual Meeting at Chicago, November 1–5, 1954.

The A. F. Davis award for 1954–55 is already underway. Any welding article written by an undergraduate and appearing in an undergraduate publication after April 1 of this year is eligible. Students in both United States and Canada may enter. For further details write direct to AMERICAN WELDING SOCIETY, 33 West 39th St. New York 18, N. Y.

Mobile Truck Holds Welding Clinics

"If the mountain won't come to Mohammed, then Mohammed will go to the mountain," might be the theme song for this field demonstration truck as it rolls along throughout the country, conducting welding clinics.

Welders invited by local dealers and distributors are brought up to date on many of the industry's newest automatic submerged arc welding and hard facing techniques, as well as being introduced to a number of the latest products marketed by the truck's sponsors.

Sponsored jointly by Mir-O-Col Alloy Co., Inc., and Pacific Welding Alloys Mfg. Co., of Los Angeles, the mobile unit is under the capable tutorship of Sid Jordan (at the wheel), well-known welding consultant. Currently the clinics are being conducted throughout the Midwest.

A question-and-answer period during each session, as well as mutual exchange of "How I solved it" or "It worked best this way for me" situations, usually highlights each clinic.

The truck itself is equipped with the latest Mir-O-Col Automatic Submerged-Arc Rebuilding Equipment, along with full lines of both Mir-O-Col Hard-Facing Rods and Pacific's Stainless and Alloy Welding Electrodes.

Irrgang Elected President of Lincoln Electric

At a meeting July 7th, the Board of Directors of The Lincoln Electric Co., Cleveland, Ohio, elected William Irrgang, President and General Manager of the Company. James F. Lincoln, elected Chairman of the Board, will remain active in the direction of company policies. John C. Lincoln, founder of the Company, now living in Phoenix, Arizona, was elected Honorary Chairman of the Board and Treasurer. Other officers elected were

J. F. Lincoln

W. Irrgang

John S. Roscoe, Executive Vice-President; A. F. Davis, Vice-President and Secretary; George Landis, Vice-President.

Irrgang becomes the third president in the 59 year history of the world's largest manufacturer of arc welding equipment. He has been Executive Vice-President since Oct. 1951. He was born in Germany and is a graduate electrical engineer of the State Technical School in Cologne. He came to the United States in 1928 and joined Lincoln in 1929. He has been engaged in various phases of plant operation, engineering and management.

He developed methods and manufacturing machinery for the mass production of welding electrodes which reduced the cost of electrodes to a point which not only established Lincoln's position in the industry but also was the key to the expansion of the welding process in metal-working industry. As Director of Plant Engineering, he was responsible for unique manufacturing methods and plant design embodied in Lincoln's new $10,000,000 plant in which the Company has been operating for the past two and a half years.

U. S. Naval Engineering Experiment Station 50th Anniversary

On Friday and Saturday, June 25th and 26th, the U. S. Naval Engineering Experiment Station at Annapolis, Md., held its 50th Anniversary Celebration. Founded in 1904, today this important Station has grown to a 59-acre site with seven major laboratories and supporting shops and facilities, having a plant value of twelve million dollars. The Welding Laboratory was organized in 1931. It is staffed by a very capable group of engineers, metallurgists, physical science aids and laboratory mechanics, under the direction of Mr. Bela Ronay (AWS), Superintendent.

The Station's 50th Anniversary was conducted under the direction of Captain

An important message concerning a new —and unique— alloy steel

UNITED STATES STEEL is pleased to announce to all steel consumers a new steel which we feel sure will enable you to improve the performance, lengthen the life, and reduce the cost of industrial equipment. This new engineering material is USS Carilloy T-1 steel, which recently underwent some very severe testing in Birmingham, Alabama.

The development of T-1 steel began back in 1947, when our research people took a good look at a problem that had plagued alloy plate steel users for years. That problem was the multiplicity of compositions required to do everyday jobs. There was no one composition available that could serve a wide variety of applications—so our research people set out to develop such a steel. The steel we wanted had to possess many unusual attributes such as very high strength, unusual toughness, good weldability and excellent resistance to impact abrasion at temperatures from minus 150°F. up to as high as 900°F.

Today such a steel is a reality. It is USS Carilloy T-1 steel, which has been tested thoroughly, both in the laboratory and in actual service applications. To prove further the capabilities of this new Carilloy steel, Chicago Bridge & Iron Company and United States Steel this summer carried out a joint testing program on commercial pressure vessels built from T-1 steel. The results of these tests and their significance to all steel users are described on the next three pages. We feel sure that you will find the story well worth reading.

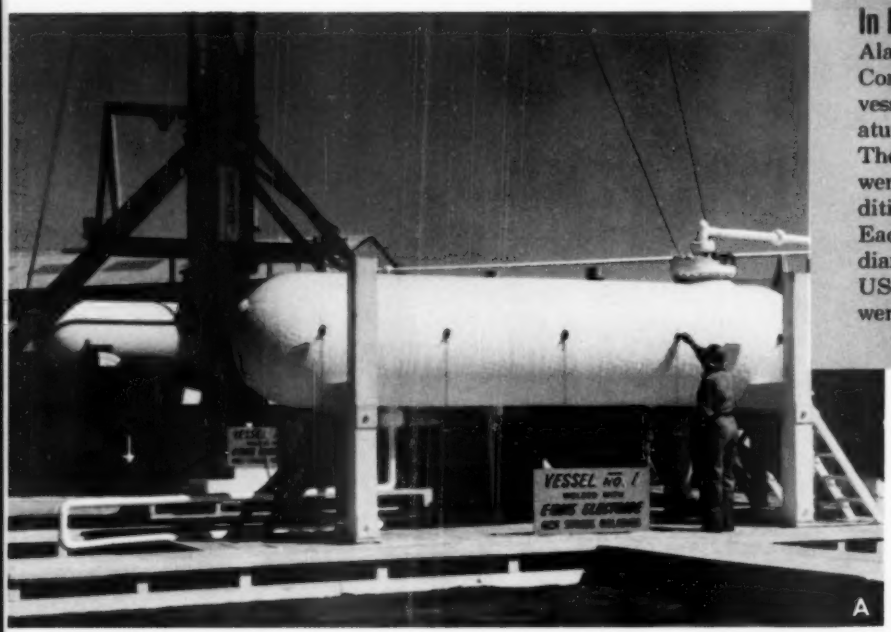
USS TRADE MARK

UNITED STATES STEEL

Remarkable new engineering material

PROVES SUPER-TOUGH

In May and June, 1954, at the Birmingham, Alabama, plant of Chicago Bridge & Iron Company, eight welded cylindrical pressure vessels were refrigerated to subzero temperatures and deliberately tested to destruction. The vessels were all standard designs that were built under normal production-line conditions by Chicago Bridge & Iron Company. Each vessel was twenty feet long, four feet in diameter, and made of half-inch plates of USS Carilloy T-1 steel. Four of the vessels were welded without stress relieving, using



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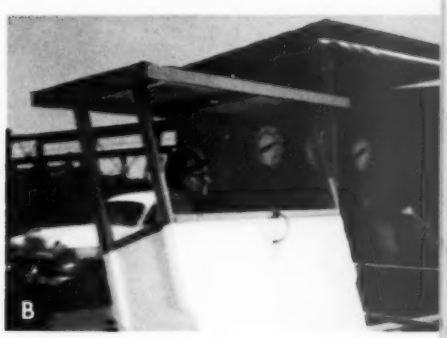
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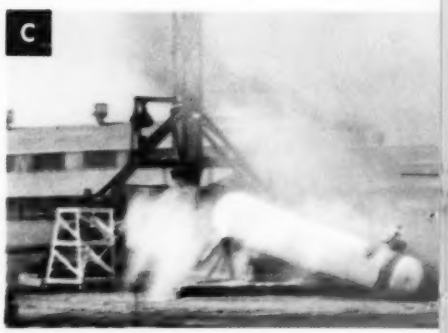
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D

In pressure test at 38°F. below zero T-1 steel withstands stresses 3 times its design strength

This vessel, not stress relieved, was refrigerated to −45°F. Then, with a quarter inch of white frost clinging to its sides, a high pressure pump slowly chugged the pressure in the vessel up to 938 psi. At that point, the steel itself was stressed to 45,000 psi., which is one half the yield strength of T-1 steel.

The hydraulic pressure was forced still higher, to 1875 psi. At this pressure, the stress in the steel had reached 90,000 psi.—the full *nominal* yield strength. Still, every inch of the metal was sound and all welds were intact.

Now the test really came. The pump labored on, and the pressure climbed to 2,000 psi. . . . to 2500 . . . to 2850 psi. . . . then . . .

BOOM! A jet of yellow brine burst out of the vessel and shot 200 feet through the air. The vessel finally failed at a pressure of 2850 psi. and a minimum stress of 136,000 psi. on the plates. This stress is well over three times the design strength of 45,000 psi.

The temperature of the steel at the time of failure was a frigid 38 below, yet the metal showed no sign of brittle failure. Super-tough USS Carilloy T-1 did what no ordinary steel could do at such a low temperature—it stayed *tough and ductile;* in fact it actually stopped the tear from propagating any further through the vessel.

USS

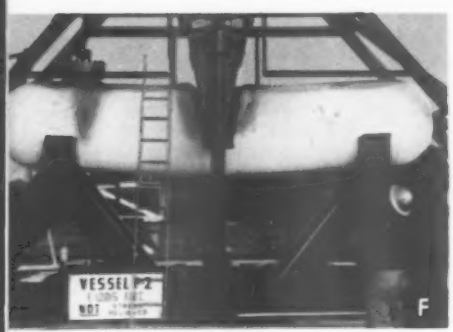
UNITED STATES STEEL

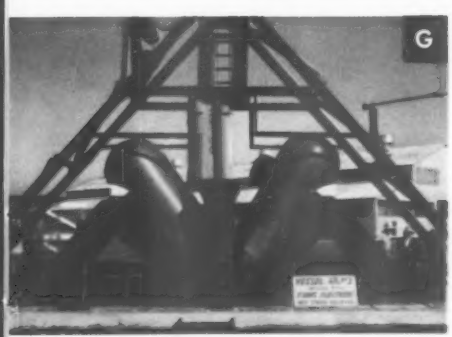
USS CARILLOY T-1 STEEL

DOWN TO 38°F. BELOW ZERO

E 12015 low hydrogen coated electrodes. The other four were welded with E 9015 electrodes and were stress relieved after welding. Two vessels of each type were given two tests: a pressure burst test for strength and ductility, and an impact punishment test for toughness and resistance to the most severe impact conditions that could be devised.

Results of these tests, described below, prove conclusively the exceptional strength and toughness of USS Carilloy T-1 steel, even at temperatures far below freezing.





Frozen steel vessel made of Carilloy T-1 survives blow from 13-ton ingot dropped 73 ft.

A steel ingot weighing 26,700 lbs. has just plummeted 52 feet and crunched on top of this test vessel (Fig. E). The ingot was traveling 39 miles per hour when it hit. It struck with an impact energy of about 1,400,000 ft. lbs., bounced fifteen feet, and crushed down again on top of the vessel.

This vessel was welded without stress relieving. It was refrigerated to 33°F. below zero. It was pressurized to 1,875 psi. equal to a stress on the plates of 90,000 psi.—the steel's *nominal* yield strength. Yet, it did not fail. The ingot left only a 7/16 inch dent in the top, with a slight bulge on either side of the dent.

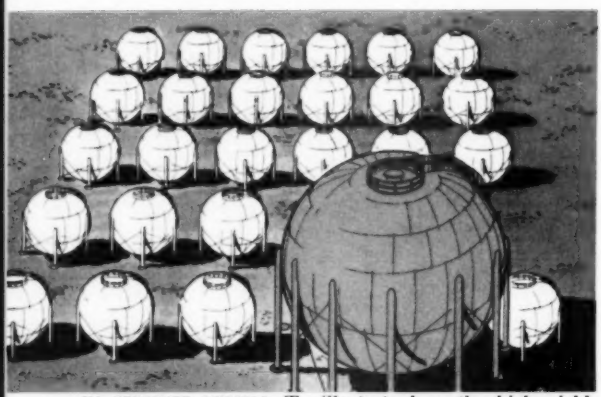
The test was repeated (Fig. F). This time the ingot was raised 73 feet, then dropped. It pounded down again on the very same spot on top of the vessel. Traveling at 46.7 miles per hour, it hit with an impact blow of 1,960,000 ft. lbs. The dent merely deepened — the steel and all welds were still intact.

Again the test was repeated (Fig. G). Now dropped from 101 feet, the 13-ton ingot ploughed into the top of the vessel at a speed of 55 miles per hour, hit with an impact of 2,750,000 ft. lbs. This time the vessel failed. But it didn't shatter. It didn't crack. It tore open like a tough piece of hickory. In other words, it failed without any signs of brittleness, even though the temperature of the steel was now minus 22°F.

In addition to this tremendous resistance to impact abuse, combined with remarkable sub-zero toughness, Carilloy T-1 steel also gives you excellent resistance to impact abrasion . . . good high temperature strength . . . and exceptional weldability.

Turn the page to see how you can use this remarkable new steel to cut costs and improve performance in a great variety of products.

Here's where you can reduce costs with USS Carilloy T-1 steel



IN PRESSURE VESSELS. To illustrate how the high yield strength of Carilloy T-1 steel can pay off here, consider this fact: To store 25,000 bbls. of propane at 210 psi would ordinarily require 25 mild carbon steel vessels. In contrast, only *one* large vessel made of T-1 steel of the *same* thickness would do the job. This single T-1 vessel would require 1/3 less shell material, 14% less foundation concrete, 70% less welding and 84% less space.

IN STEEL MILLS. In skip cars, T-1 steel in the bottoms, sides, and bail plates lasts three times longer than steels now in use. T-1 steel also gives exceptionally long service in coke bins and chutes, in ore transfer cars, in draft lines, in conveyor chains, and crane hooks. In clamshell buckets, T-1 steel has taken heavy abuse at temperatures from 500° to 600° F. and lasted *nine times* as long as the wear resisting steel previously used.

IN EXCAVATING EQUIPMENT. The dipper stick, bail, and bucket of this big electric shovel are fabricated of T-1 steel plate. The superior strength and durability of Carilloy T-1 made it possible to increase the capacity of the bucket from 35 to 45 cu. yds.

• The pressure vessel tests described on the previous pages indicate only one of the many possible uses of Carilloy T-1 steel. For this new engineering material has advantages not only in pressure vessels and storage tanks, but it also has proved itself in power shovels, bulldozers, mining machines, mine cars, steel mill ladles, blast furnace draft lines, lift trucks—in high speed rotating machinery, in stamping or forging presses. It is being considered for use in tension members of cantilever bridges and other similar applications where tension members are involved.

With the 90,000 psi. minimum yield strength to work with, combined with extraordinary sub-zero toughness, good high temperature strength to 900° F., and excellent resistance to impact abuse, impact abrasion, and atmospheric corrosion, you can use T-1 steel to reduce the size and weight of heavily stressed parts. This cuts your shipping and handling costs, as well as the cost of material, and the cost of foundations and supports where they are needed. Carilloy T-1 steel lengthens the life of your equipment, cuts repair bills and outage time. And remember, wherever you use T-1, you can weld or flame cut it either in the shop or in the field without expensive heat treating equipment. This cuts costs still further.

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COLUMBIA-GENEVA STEEL DIVISION, SAN FRANCISCO
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UNITED STATES STEEL SUPPLY DIVISION, WAREHOUSE DISTRIBUTORS
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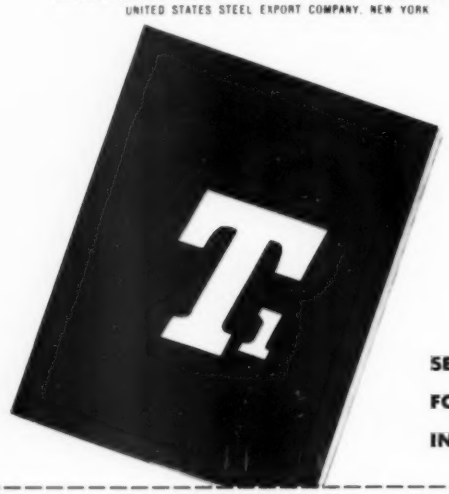

SEND COUPON FOR COMPLETE INFORMATION.

United States Steel, Room 4481
525 William Penn Place
Pittsburgh 30, Pa.

☐ Please send me your booklet "United States Steel presents T-1" which contains the full story of T-1 steel.

☐ Have your representative get in touch with me.

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USS

UNITED STATES STEEL

Fred W. Walton, U.S.N., Station Commanding Officer and Director, who also presided at the Ceremonial activities, introducing, as honored guests, Honorable T. R. McKeldin, Governor of Maryland, Vice Admiral Roscoe F. Good, Deputy Chief of Naval Operations (Logistics), James G. O'Neill, Retired Superintendent, EES Chemical Engineering Laboratory, and Rear Admiral Wilson D. Leggett, Jr., Chief, Bureau of Ships.

Over 1000 guests heard Admiral Leggett review the history and acclaim the past half century's accomplishments of the Station. This important activity was a dream of Admiral George W. Melville, transformed into a reality of today. In 1887, Melville wrote, "It is important that exhaustive experiments be made in scientific manner....no vessel can be a finality under any condition." Admiral Leggett pointed out that research and development may be likened to the formula for rabbit stew; 50-50; that is, one horse, plus one rabbit. In direct parallel, development is the horse! He stressed that creative thinking is the hardest work and that at no time dare we discount the ability of our potential enemies. They have adopted a laboratory development system similar to ours, and with their own and their captive mind-power, can parallel our output. On an equal basis, that which they develop will be, in their hands, far more dangerous than the equivalent in ours, in that their advantage lies in their ability to concentrate on the "offensive," whereas we must provide for the "defensive" and retaliation. He further cautioned that the advent of nuclear power solves nothing, but rather adds to our problems as we now not only have those but also all of the old ones. We must check all by-roads and realize that our research and development activity can never be completed.

In Building No. 120 were exhibited more than 100 displays depicting the Station's work. During both days, these were exhibited, and many demonstrated, to 3500 guests and Station personnel and their families, the guests, including industrialists, scientists, educators, and representatives of various federal activities. The Welding Laboratory exhibits were outstanding and very well displayed in educational fashion, aided by clever and professional-type cartoons. In additional the Welding Staff conducted educational tours through their laboratories on both days.

Assisting Mr. Ronay on the planning, construction and manning the excellent welding exhibit, and the conducted tours through the Welding Laboratory, were the Laboratory's Staff, including Mr. J. Henry Siegel, Assistant Superintendent, Messrs. W. H. Clautice, F. X. Henderson, Raymond Phebus, Oscar Swenson and Mrs. R. F. Payne, Welding Engineers, Messrs. Francis Carter, Joseph Hopkins, Leonard Leatherbury, Gordon Phipps and Robert Stevens, Physical Science Aides, Messrs. J. W. Courtney, George Fowler, John Vanssant, Marcel Weidman, Calvin Wietzel and Carl Youngren, Laboratory Mechanics and Mr. R. W. Miller, Xographer, who also was responsible for the excellent cartoons which graphically or symbolically, in humorous but withal educational vein, made the technical phases of welding research and development clear to the layman. Great care was exercised to keep the cost of the display at a minimum without impairing their educational value. In all the activity was not only beneficially educational but was very well organized, highly successful in accomplishment and productive in attendance.

Bureau of Shipping Meeting

The Semi-Annual Meeting of the Board of Managers of the American Bureau of Shipping was held on July 27 in the board room of the Bureau at 45 Broad St., New York City.

Walter L. Green, Chairman of the Board and President, presided and expressed his appreciation to the Board of Managers of their attendance.

The following were elected to the Membership of the American Bureau of Shipping:

Richard L. Burk President, Sun Shipbuilding & Dry Dock Co., Chester, Pa.

Winthrop O. Cook, President, Seas Shipping Co., New York, N. Y.

Cecil H. Gay, Vice-President, Babcock & Wilcox Co., New York, N. Y.

John F. Gehan, Executive Vice-President, American Export Lines, New York, N. Y.

George Peterkin, Jr., President, Dixie Carriers, Inc., Houston, Texas.

In his remarks, Mr. Green said:

Bureau Activity

"There now exist in Class with the American Bureau of Shipping 7610 vessels of 38,624,772 gross tons, an increase of 600,000 tons over the total at this time last year. About 22% of these vessels is temporarily inactive.

Foreign Business

"In June of this year the French Government issued a decree officially recognizing the American Bureau of Shipping, permitting us to assign load lines and to issue load line certificates for vessels registered in France, under the provisions of the International Load Line Convention (1930).

"The Bureau's business in foreign ports has been maintained at a satisfactory level, although the volume of new construction has been declining.

"A total of 53 new vessels were completed to Bureau Class in overseas shipyards during the first half of this year, these aggregating 492,983 gross tons. A like amount of tonnage should be completed in the last six months of this year. This total has been steadily increasing in each of the postwar years.

"New vessels building to Bureau Class in European and Japanese shipyards now aggregate 151 of 1,627,889 gross tons, a decline of 400,000 tons since one year ago. This represents more than two-thirds of our total new business now in hand, compared to 60% twelve months ago.

Technical Activities

"In the laboratory maintained by the Bureau our program of checking the quality of steel being supplied to shipyards under the Bureau specifications is still one of the major activities. This program has continued to indicate that the present specifications are effective in precluding the supplying of steel plates of undesirably high notch sensitivity. The maintenance of the laboratory is proving to be of inestimable value in that the staff is able to study at first hand, and to make available to our Committees, the properties of steel manufactured under newly developed processes which are becoming of increasing importance in the steel industry throughout the world.

"The Bureau has continued to maintain its close relationship to an active participation in the activities of the various technical organizations which have direct, or even only remotely related, interest in problems encountered in the design and operation of ships, their machinery, and appurtenances.

"During their trip to Europe Mr. Brown and Mr. Gatewood had the opportunity of visiting a number of shipbuilding and manufacturing plants in many of the areas where there are vessels under construction to Bureau Classification. While on this same trip, they, accompanied by Mr. B. A. McLean, the Principal Surveyor for Italy and Western Mediterranean Ports, acted as members of the delegation from the United States attending the annual meetings of the International Institute of Welding in Florence, Italy. In accordance with the apportionment of duties among the United States delegates, they attended meetings of the various Commissions operating under the auspices of the International Institute of Welding and entered into the discussions and exchange of ideas which took place at these meetings.

Shipbuilding

"A postwar production record, and a probable all-time peace year peak, was established in 1953 when shipyards of the world completed 608 merchant vessels of 4,579,000 gross tons and 6,501,000 deadweight tons. This includes only seagoing vessels of 1000 gross tons and over. The indications are that in 1954 at least an equal amount of tonnage will be produced.

"In each of the eight postwar years there has been a constant increase in pro-

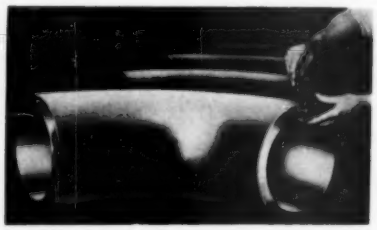
duction. The grand total of vessels constructed in that period was 3572 vessels of 23,171,000 gross tons and 32,068,000 deadweight tons. About 41.8% of this tonnage was oil tankers, 46.1% freighters and 12.1% passenger ships.

"On a gross tonnage basis, shipyards of the United Kingdom led with the greatest production last year, turning out 27.1% of the grand total delivered. Japan was second with 15%, followed by Germany with 14.2%, the United States with 10.8% and Sweden with 10.2%. Other nations accounted for the balance, with none over 5.7% of the total.

"Shipyards of the United States should, according to present building schedules, complete this year a near record peacetime total of merchant ship tonnage and possibly exceed the record production of 1953 which was over 880,000 deadweight tons. Major size vessels already delivered by American shipyards in the first six months of 1954 total 21 of 285,528 gross tons and 443,648 deadweight tons, equipped with propelling machinery of 335,700 horsepower."

Piping of First Atom Powered Submarine

The launching of the world's first atom propelled submarine, the Nautilus, on Jan. 21, 1954, wrote a momentous chapter in naval history. It also marked another decisive engineering achievement by Westinghouse, which built the submarine's nuclear power plant.



The Nautilus' engine consists of a nuclear reactor, pumps, piping and other components. Water of the primary system is piped into the reactor where it is heated and carried to a heat exchanger. There, water of the power system is converted into heated steam. The steam operates a turbine connected to the propulsion mechanism.

Of particular interest is the piping employed in the nuclear power plant. It is fabricated of Type 347 stainless steel, to assure maximum service life under the critical conditions encountered. Flow impediments are minimized, joint leakage eliminated and space saved by making directional changes with *Tube-Turn* welding fittings, produced by Tube Turns, Louisville, Ky.

Head for World's Heaviest Process Vessel

Loaded on flat cars, one-half to a car, the bottom head for the heaviest process vessel ever designed recently left the Jersey City shops of The M. W. Kellogg Co. for its destination in Ind. The photograph above was taken just prior to shipment as a vertical strut pipe was being fitted into one of the halves of the huge head to prevent distortion during transit.

Each half of the head consists of four "orange-peel" sections of carbon-moly

steel plates, $2^3/_4$ in. in thickness, which were formed by The Lukens Steel Co., Coatesville, Pa. The sections were then shipped to Kellogg, a subsidiary of Pullman, Inc., where they were cut to exact size and welded together.

At the job site the halves will be joined to form the bottom of the reactor vessel for a 30,000 barrels-per-day Fluid Hydroforming plant now under construction by Kellogg. The reactor vessel will be approximately 135 ft high with an internal diam of $23^1/_2$ ft. On top of this will stand a smaller vessel in which catalyst for the reforming process is regenerated. When completed, the unit will tower more than 200 ft above its supporting pedestal.

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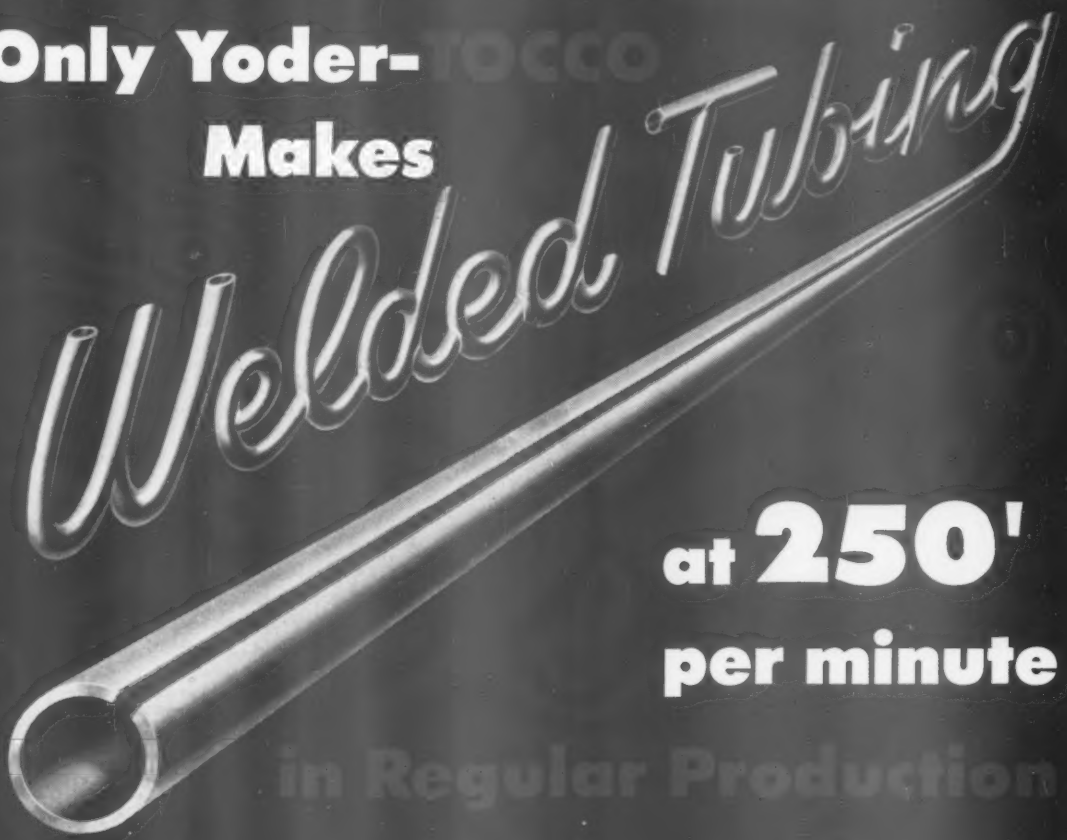

Yoder—TOCCO mills, using the patented TOCCO Process for welding ferrous pipe and tubing are actually producing pipe at speeds of 150 to 250 feet per minute. This rate is almost twice as fast as any other cold forming pipe mill in production anywhere in the world. *Check these advantages:*

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PERSONNEL

A. F. Davis Honored

A. F. Davis (r), Vice-President and Secretary of the Lincoln Electric Co., Cleveland, has a chuckle with the man who has been his boss for the past 40 years, J. F. Lincoln (l), Chairman of the Board. The chuckle is over a letter received by Davis from one of his associates on the occasion of his 40th anniversary with the company, July 1, 1954. Over 250 of his associates wrote him letters that day, which were presented to him by Mr. Lincoln in a hand-tooled leather bound book. Nearly 100 of them gathered in the evening to honor him with a dinner at which he was presented a desk pen set.

Davis has been Vice-President of Lincoln since 1925. He has been responsible for the company's educational program which has been important in the last 30 years in the development and expansion of the welding industry. One phase of the program has been the publishing and selling of over 1 million copies of technical books on various aspects of arc welding. He has operated the Lincoln Welding School since 1917 and published, since 1926, the *Stabilizer*, a magazine sent to welders all over the world. He also is Secretary of The James F. Lincoln Arc Welding Foundation which was created by the company in 1936.

Louis M. Hardnack Made Superintendent

The Paterson-Leitch Co. of 900 East 69th St. announce that Louis M. Hardnack assumed the position of Plant Superintendent and will be in complete charge of all phases of their plant operations.

Mr. Hardnack comes to the Paterson-Leitch Co. with many years of valuable steel fabricating experience, among his

former employers are the American Bridge Co., Bethlehem Steel Co., Thew Shovel Co. and T.P.V. Co.

Mr. Hardnack is a member of the AMERICAN WELDING SOCIETY. He is a native Pennsylvanian and at present resides in Amherst, Ohio.

Lutz Promoted

Kenneth V. Lutz, recently of San Jose, Calif., has been appointed General Sales Manager of All-State Welding Alloys Co., Inc. Announcement of his promotion was made by Mr. Thomas D. Nast, president.

Mr. Lutz will direct sales and service to users and distributors of All-State Alloys and Fluxes, and also the establishment of additional such facilities when needed.

Of the six years Mr. Lutz has worked with the All-State organization, the major portion was as Regional Manager for

eleven western states and Hawaii, where he conducted some 170 All-State clinics and 1600 plant demonstrations. He then became General Field Manager. In previous employment he was in charge of sales, demonstrations, and technical service on All-State products for Welders Supply Co. in Seattle; shop foreman at Ferrofix Welding and Engineering Co., Seattle; Leadingman Welder, Puget Sound Naval Shipyard; Welding Supervisor, Winslow Marine Shipbuilding Corp., Bainbridge Island, Wash.; and Senior Inspector Ship Construction (welding), U. S. BuShips.

Mr. Lutz completed a course in Welding Engineering at the Univ. of Wash. and has been a member of the AMERICAN WELDING SOCIETY since 1940. He had taken up welding in 1935 while in the Navy aboard the battleship U.S.S. West Virginia.

OBITUARY

H. S. Smith

Mr. H. Sidney Smith, formerly of the Union Carbide and Carbon Corp., and one of the founder members of the AMERICAN WELDING SOCIETY, died at his home in Larchmont on May 14, 1954 following a prolonged illness.

Sid Smith was an outstanding figure in the welding and cutting industry in the United States and abroad for nearly fifty years. He served long and well as a member of the Board of Directors, a member of the Executive Committee, and a member of numerous technical and standing committees. He was also Past-President of the International Acetylene Assn., The British Acetylene Assn., and the Compressed Gas Manufacturer's Assn. Mr. Smith was awarded both the Samuel Wylie Miller Medal of the AMERICAN WELDING SOCIETY and the Morehead Medal of the International Acetylene Assn. and was the first person to receive these two outstanding awards of the welding industry.

Mr. Smith was born in Newark, England, and was educated at Nottingham University, where he studied electrical engineering. In 1896 he joined the Acetylene Illuminating Co., Ltd., which was experimenting with the manufacture of calcium carbide. He assisted in the preliminary experiments there, and in conjunction with S. G. Worth (the founder of the British Acetylene Assn.) produced the first calcium carbide made in Great Britain on a commercial scale.

He became General Manager of the Acetylene Illuminating Co., Ltd., and also of the British Autogenous Welding Co., Ltd., and in 1910 he was elected President of the British Acetylene Assn. The next year he came to America and joined the Prest-O-Lite Co., Inc., in Indianapolis, Ind., becoming Works Manager in charge of all gas plants. In 1918 he became Consulting Engineer for Union Carbide Co.

In his career with the Union Carbide and Carbon Corp. and its associated companies, he has made many important contributions to the oxyacetylene industry, and has been the author of numerous technical articles on the uses of oxygen, acetylene, calcium carbide and oxy-acetylene apparatus, one of the first instruction manuals on oxy-acetylene welding and cutting being written by Mr. Smith.

On the subject of industrial safety and fire prevention he has worked actively with insurance and regulatory bodies in developing and applying rules and procedures to improve the safety standards of the industry. Mr. Smith's work has contributed greatly to the acceptance of the oxyacetylene and the compressed gas industries as being among the best regulated of American industries from the standpoints of safety and accident prevention.

Mr. Smith was made honorary member of the AMERICAN WELDING SOCIETY in 1947.

H. L. Whittemore

Taken largely from the Herald Tribune Bureau

Herbert L. Whittemore, seventy-seven, retired chief of the engineering mechanics section of the National Bureau of Standards, died of cancer July 11th. in George Washington University Hospital.

Mr. Whittemore was appointed chief of the section in 1917 by President Woodrow Wilson to direct mechanical tests of large quantities of war materials. He held the post until he retired in 1946.

He invented the Whittemore fulcrum plate strain gage for measuring stress on concrete dams and large steel structures. He helped design the Whittemore-Petrenko proving ring, now standard equipment for checking the accuracy of tension and compression testing machines. Before his retirement, Mr. Whittemore conducted a program for testing prefabricated housing components.

Born Oct. 1, 1876, in Milwaukee, Mr. Whittemore studied at the University of Wisconsin. He taught mechanics at the University of Illinois and Columbia University. Later, he was appointed a professor at the University of Oklahoma.

Author of numerous papers and books on subjects within his field, Mr. Whittemore was the recipient of many honors from professional societies of which he was a member.

Survivors are his wife, Dr. Elizabeth A. Kittredge Whittemore, a physician; a daughter, Miss Nancy Whittemore, of Washington; a son, William Kittredge Whittemore, of Cleveland, and a sister, Mrs. Anne Von Ammon, of Washington.

Professor Whittemore was very active in the early days of the formation of the AMERICAN WELDING SOCIETY. He served as the Chairman of the Awards Committee of the Society and was in direct charge of many of the research investigations of the old American Bureau of Welding, predecessor of the Welding Research Council.

WELDABILITY OF STEELS

An outstanding summary of current knowledge of the Weldability of Carbon & Low Alloy Steels prepared by Drs. R. D. Stout and W. D'Orville Doty under the direction of the Weldability Committee of the Welding Research Council.

Book of 381 pages including tables for welding ASTM, SAE, ABS and other specification Steels in all thicknesses.

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Five grades of Ampco-Trode filler rod give you good welds with practically any hardness you need. Here's the selection:

Filler Rod	Deposit hardness (BHN 3000 kg. load)
Ampco-Trode 10	160-190
Ampco-Trode 160	190-220
Ampco-Trode 200	250-280
Ampco-Trode 250	310-340
Ampco-Trode 300	350-380

Use Ampco-Weld Flux with inert-gas processes. Ampco-Weld Flux removes surface oxides, lowers the amount of preheat and current, speeds welding. Keep your welding surfaces clean and dry to make the highest quality welds.

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NEW LITERATURE

Ampco Welding News

Free copies of the Second Quarter issue of the 1954 Ampco Welding News are available upon request from the Ampco Weldrod Department.

This most recent issue features such interesting articles as, "Caterpillar Welds Galvanized Iron with Ampco-Trod 10," "Cast Iron Reject Lifters Welded with Ampco-Trode 10," and "2,000,000 Chair Seats Drawn over Ampco-Trode 300." In addition to these feature articles, there are several informative short articles on new products, practical applications and welding techniques.

Please send your request to Ampco Metal, Inc., 1745 South 38 St., Milwaukee 46, Wis.

Resistance Welder Bulletin

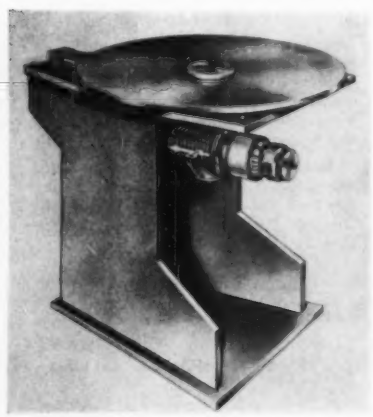
New dual-head resistance welding machines which maintain two complete setups with instantaneous change-over are described in Bulletin 10905, just published by the Universal Welder Corp., Cleveland 4, Ohio.

Available on request, the new bulletin delineates typical combinations of seam, roll-spot and projection welding—either longitudinal or circular—which are accommodated by these machines.

Complete dimensional and working data is listed for the 50 to 200 kva size range of these welders, which are also available in ratings to 400 kva.

Resistance Indexing Unit

Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., Bulletin No. 319-12 on the Sciaky Dial Feed, the universal, rotary indexing unit for all applications on resistance welders, machine tools, and various assembly operations.



The new Sciaky Rotary Indexing Unit for dial feed applications provides an extremely simple, most efficient system which completely replaces all previous dial feeds.

For more complete information with application references write for Bulletin No. 319-12.

How to Do It

A new "how-to-do-it" book, 24 pp., 4 x 7 in., illustrated, has been published by All-State Welding Alloys Co., Inc. The publication is titled "Brazing Manual" and is particularly addressed to the service trades. It contains data for brazing shapes, sheet, castings, tubing and assemblies of copper, brass, steel, aluminum and cast iron. Consequently, it will be helpful to all who have such work to do, and also to others who have the problem of teaching torch operators what they need to know in order that the most can be gotten out of the alloys and fluxes designed for brazing.

Copies of the new manual are available without obligation from All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y., and from All-State distributors throughout the country.

Constant Voltage Welding

Factual data describing the principle of the Constant Voltage power supply and its application to inert-gas, submerged-arc and other automatic welding processes is given in a series of data sheets just published by the Glenn Co., 3134 E. 10th St., Oakland 1, Calif. Included is a report on "Constant Voltage Control for Automatic Metal Arc Welding." by L. P. Henderson, Welding Engineering Consultant. The six data sheets are in standard $8^1/_2$- x 11-in. form for easy reference and filing. Copies of the series may be obtained without charge from the Glenn Co.

Tempilstik° Instructions

Tempil° Corp., 132 West 22nd St., New York 11, N. Y. has recently revised their Tempilstik° instruction sheet. The new version critically examines the factors which affect temperature indication by means of Tempilstiks°. Useful, ingenious suggestions on how to determine temperatures in a number of special cases are described. Some of the topics covered are:

1. Effects of long continued heating on a Tempilstik° mark.
2. Melting versus color change.
3. When Tempilaq° or Tempil° Pellets should be used in preference to Tempilstiks°.
4. Can Tempilstiks° be used to determine temperatures of a cooling object.
5. Effects of electrical fields and ionized air.
6. How to use Tempilstiks° on smooth or polished surfaces.
7. Effect of reducing atmospheres.
8. Using Tempilstiks° to obtain the temperature distribution of a surface.
9. Temperature of rapidly rotating or moving objects.
10. Visibility on a brightly radiating hot surface.

Copy available on request.

K-G Abbreviated Catalog

The abbreviated catalog—No. Q54E—has just been released by the K-G Equipment Co. (Inc.). The catalog is available from the manufacturer on request to Mr. Karl H. Schmuldt, General Sales Manager, The K-G Equipment Co. (Inc.), Post Office Box 538, Allentown, Pa.

Hard-Facing Data Book

A comprehensive and analytical study of hard-facing, its application and its wear-resisting qualities wherever impact and abrasive conditions exist, is contained in a new 72-page pocket size brochure just off the press.

Published by the Mir-O-Col Alloy Co. of Los Angeles, Calif., this brochure incorporates the latest data and instructions on hard-facing, as well as new information about Mir-O-Col's own line of hard-facing metals. A special section of the report, the application index, recommends specific hard-facing rods for over a thousand individual pieces of equipment subject to impact and abrasion.

The technical data section of the profusely illustrated brochure is written by experts in the field of hard-facing. It records vital information such as What metals can be hard-faced, Effect of heat on metals, Depositing single narrow heads, Hard-facing with moderate build-up, and other pertinent technical information.

Copies of this graphic 72-page pocket size brochure may be obtained without cost or obligation, by writing to the Mir-O-Col Alloy Co., 312 North Ave. 21, Los Angeles 31, Calif.

Temperature Measurements

Tempil® Corp., 132 West 22nd St., New York 11, N. Y. has made available a reprint of "How Temperatures Are Measured" by Dr. G. M. Wolten.

This is an interesting and informative discussion of a subject about which there is a great deal of misunderstanding and confusion even among the technical fraternity. Some of the topics covered are:

1. Heat and temperature as separate concepts.
2. History of the commonly used scales for measuring temperatures.
3. Physical effects associated with a rise in temperature; how thermometers and pyrometers utilize some of these effects.
4. Monitoring surface temperature by means of changes in color or physical state.

Copies available on request to the Corporation.

Safety Ideas

The National Safety Council's new book, "Safety Devices and Ideas," describes more than 90 safety devices which have been tried and found effective in plant use.

The devices were originally part of a safety gadget show presented during the chemical sessions of the 1953 National Safety Congress. Although designed for use in chemical plants, the devices have application in other industries as well.

Most of the devices are not commercially available, having been thought up and constructed by plant personnel to meet some particular hazard.

Each idea is illustrated with a large photograph which shows clearly the details of construction. The test accompanying the pictures gives other pertinent data.

"Safety Devices and Ideas" is available for $1.25 to Council members and $2.50 to others. For further information write the National Safety Council, 425 N. Mich. Ave., Chicago 11, Ill.

Engineering Applications of Ductile Cast Iron

Bulletin DI-2, 8 pages with illustrations, presents data on machinability, gall resistance, compressive strength and other mechanical properties of this recently developed family of irons which possesses the process advantages of cast iron and which has engineering properties that approach those of cast steel. Examples are given illustrating the appropriate use, in the design of machine components, of one or more of its properties including its ability to combine a chilled surface (55 Rockwell C hardness) with a ductile core or back (10% elongation). International Nickel Co., New York 5, N. Y.

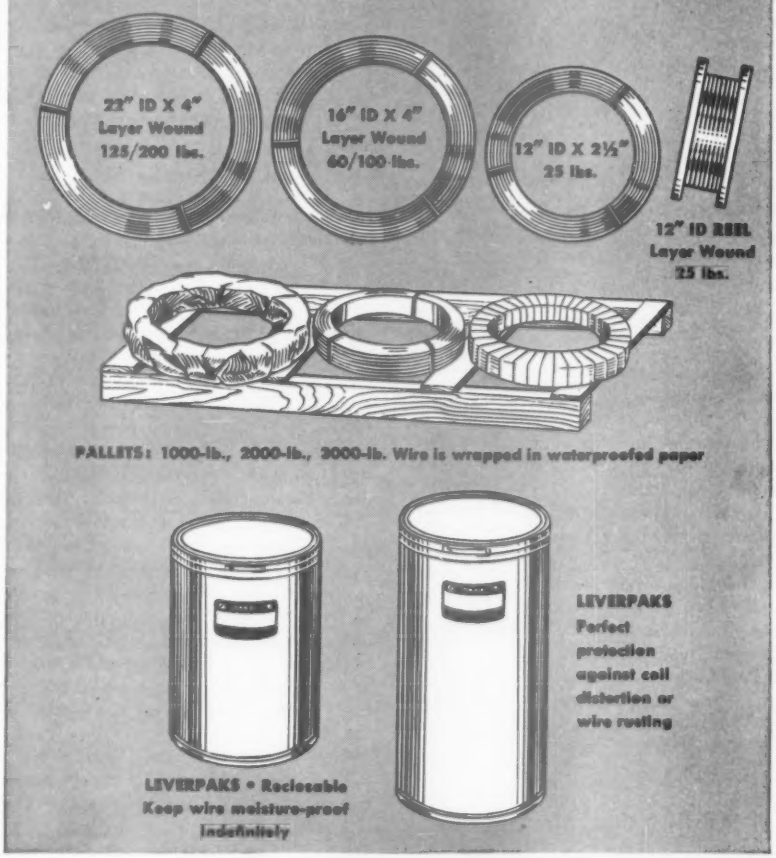
Page Welding Wire

PAGE CHECK-OFF

Check the welding wire you use:

- ☐ Heavy submerged arc
- ☐ Light manual submerged arc
- ☐ Inert gas manual or automatic

HOW TO BUY IT



CARBON STEEL • Any carbon from Armco (.025 max.) to high carbon (.90-1.10). All standard AISI analyses in between.

LOW ALLOYS • All the most popular welding grades.

STAINLESS • AISI—308, 309, 310, 316, 347, 410, 420, 430 and 502. Other types on request.

• PAGE also offers all of these analyses for oxyacetylene gas welding, metal spray wire, or bare electrodes.

Write today for detailed literature and prices

Page Steel and Wire Division

AMERICAN CHAIN & CABLE

ACCO

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Portland, Ore., San Francisco, Bridgeport, Conn.

NEW PRODUCTS

Speed Electrodes

The Champion Rivet Co., Cleveland, 5, Ohio, announces the marketing of their new "Speedemon" line of welding electrodes.

According to the manufacturer, Champion is the first to bring the advantages of the "touch type" electrode to the hard-surfacing field with Speedemon No. 500. This electrode produces tough, sound, porosity-free welds on mild, high carbon, cast steel and manganese steel. Deposition rate, it is claimed, is over 50% greater than with conventional hard surfacing electrodes. The "drag" technique of application makes for easy, fast handling.

Applications of Speedemon No. 500 include gears, pinions, rock crushing equipment, road building machines, dipper teeth, bucket lips, tractor treads and lugs, etc.

Champion Speedemon No. 12 electrodes are also of the "touch type" with high iron powder content coating. Deposition rate is said to be 20—35% higher than that produced by ordinary mild steel electrodes. Speedemon No. 22, according to Champion, greatly increases welding speeds and reduces cleaning time to a minimum.

This electrode is recommended for horizontal and positioned fillets, lap welds, groove welds and cover pass work. It is available in $^1/_8$-in. through $^1/_4$-in. diam.

Full information may be obtained by contacting the Champion Rivet Co. 10819 Harvard Ave., Cleveland 5, Ohio.

Chamfering Electrode

A new high-speed chamfering electrode announced by All-State Welding Alloys Co., Inc., 249-55 Ferris Ave., White Plains, N. Y. has the outward appearance of a heavy bar, it is so thickly coated with flux.

The new electrode is reported to be one of the fastest for chamfering, gouging, bevelling, routing and channeling . . . a high-speed means of removing excess metal, gouging out old welds, preparing joints to be welded, routing out high-chrome welds on dipper teeth, armor plate, etc.

This fast metal-removing rod is for ac or dc (straight polarity on dc). Each rod will make a groove its own length and with a top width equivalent to its own diam. The heavy coating of flux (about three times usual) is especially compounded to protect the rod against overheat at high amp and also to lend heat to the arc when ignited by it. The flux has a large part in the smooth fast chamfering action. Surfaces chamfered with it are ready to weld with little or no cleaning required.

The new electrode is designated as the All-State High-Speed Chamfer Rod. It is used without oxygen or compressed air . . . therefore minimizes oxidation. It is now available through all All-State Distributors in $^1/_8$, $^5/_{32}$ and $^3/_{16}$-in. core sizes. Length is 14 in. Standard packages are 25 pounds.

Silver Solder Flux

The Superior Flux & Mfg. Co., after a prolonged research and testing program now offers a new silver solder flux. This new flux was developed for "out of the ordinary applications," where standard "everyday" fluxes are not satisfactory. This new flux is intended to supplement Superior's patented and well known No. 6 Noncorrosive Silver Solder Flux and No. 66.

This new flux, No. 601 is a high temperature, 1800° to 2000° F, long cycle flux. Superior 601 was found to be the only flux which would do a perfect job on an Air Corps part which consisted of a 18 in. diam stainless steel housing to which a large number of blades had to be attached. Brazing with a torch was the only practical way of attaching these blades. Due to the thinness of the blades and the thickness of the housing, quite a bit of localized overheating was created in the blades.

Flux residues are easily removed by flushing with hot water. Manufacturer will send samples upon request. Write to: The Superior Flux & Mfg. Co., Dept. Y-11, 1302 Ontario St., Cleveland 13, Ohio.

Electrode for Hard to Weld Steels

Excellent weldability and fast high tensile build-ups of many hard-to-handle alloy and cast steels are two outstanding features of the newly developed Matrix electrode.

Offered by Pacific Welding Alloys Mfg. Co., of Los Angeles, the new Matrix electrode is a conglomerate alloy containing carbon, manganese, chrome, nickel, molybdenum and vanadium, with a low hydrogen type coating.

The Matrix's rapid bonding qualities makes it unsurpassed for build-up of various hard-to-weld work preparatory to final pass with hard-facing electrodes.

Deposits of the Matrix electrode have a Rockwell C hardness of 28 to 30 and are readily heat treated for desired hardness and physical properties. Machinability of the electrode is rated as excellent. The electrode is best applied with ac or dc reverse polarity with a close arc.

Pacific's Matrix electrodes are currently available in $^1/_4$, $^7/_{32}$, $^3/_{16}$, $^5/_{32}$ and $^1/_8$ in. Free samples along with descriptive literature of the electrode will be sent upon request to Pacific Welding Alloys Mfg. Co., 310 North Ave. 21, Los Angeles 31, Calif.

Build-Up Rod

A new shielded arc electrode, the Mir-O-Col 4T, developed specially for build-up of worn tractor rails and grousers is now being marketed by the Mir-O-Col Alloy Co.

Noted for its medium abrasion and very high impact resistant qualities, the Mir-O-Col 4T gives a highly ductile deposit that will not chip, spall or part from the base metal.

The new electrode, packaged in 10-lb containers for protection against moisture pick-up, scuffing and rusting is best applied with a c-d c reverse polarity at 160 amp—$^3/_{16}$-in. rod.

Free samples of the electrode along with descriptive literature may be obtained by writing to Mir-O-Col Alloy Co., 312 North Ave. 21, Los Angeles 31, Calif.

Cast-Iron Rod

A new copper-coated cast-iron welding rod, metallurgically compounded so that the average torch welder can easily get strong (48,000 psi, tensile) machinable welds that are free of blowholes, is announced by All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y.

Identified as All-State No. 3 General Purpose Cast-Iron Rod, this new product is recommended for repairing breaks and cracks, filling blowholes, building up worn parts and for other salvage or production work. No. 1 Brazaloy Flux powder is needed. With these two products together, maintenance and production welders alike can produce good joints without melting the base metal or "puddling the weld."

No. 3 is available at all All-State Distributors in $^3/_{16}$ and $^1/_4$ in. diam. Rod length is 18 in. Standard package is 10 lb.

The A. O. Smith *Heavy-Duty* A. C. Welder

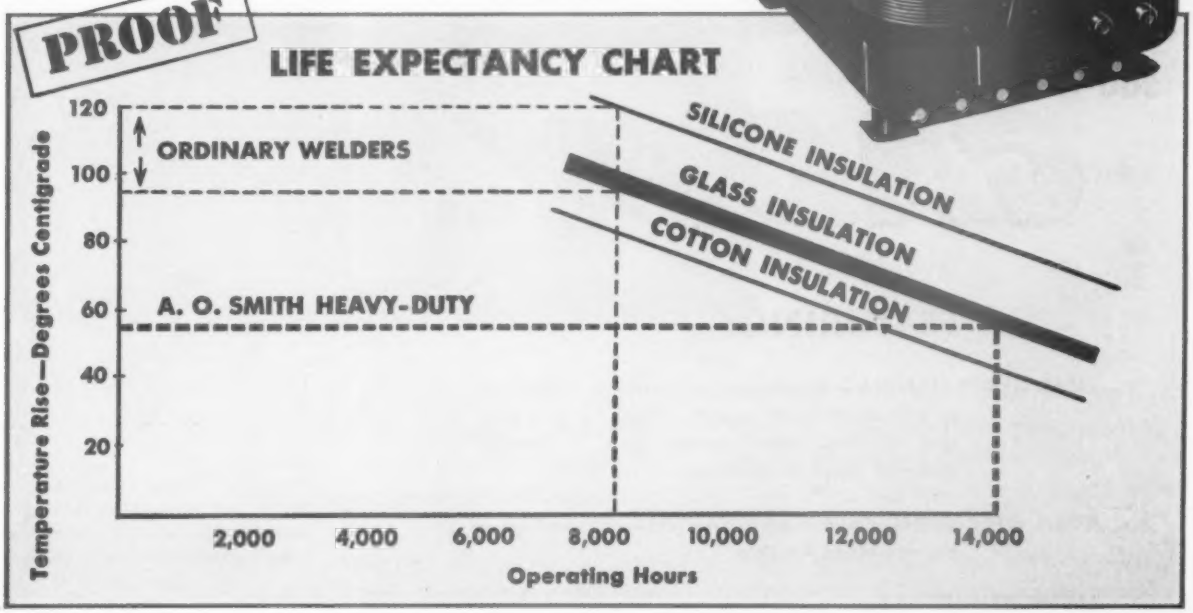
6000 hours longer life

than any other A. C. welder

Available in 300-, 400-, and 500-Amp. models.

PROOF

LIFE EXPECTANCY CHART



Temperature Rise Determines Machine Life

According to the Insulation and Aging versus Temperature Curves, as published by the A.I.E.E. . . . *the cooler a welding machine operates, the longer its production life.*

The A. O. Smith Heavy-Duty is the *only* A. C. welder on the market with enough copper and cooling capacity to operate without exceeding a 55° C. temperature rise—as compared to the 90° C. rise allowed by N.E.M.A. for glass-insulated welders.

This means: This welder will give you top production efficiency almost twice as long as any other A. C. welder on the market today.

Built for those who want the best in welding, the Heavy-Duty has a full 75 open circuit volts, high-velocity down-draft ventilation, all-weather case, 12½ KVA power factor correction and stepless current control.

For additional information on welding machines, electrodes and accessories, see your local A. O. Smith distributor or write to A. O. Smith Corporation, Welding Products Division, Milwaukee 1, Wisconsin.

A.O.Smith
CORPORATION

WELDING PRODUCTS DIVISION
Milwaukee 1, Wisconsin
INTERNATIONAL DIVISION: MILWAUKEE 1
Made by welders . . . for welders

Another CADDY FIRST

Molded FIBER GLASS HANDLE

The COOLEST operating lightest weight (14 Oz.) tong type holder ever made

300 AMP

CADDY® CUB

FEATURING:

FIBER GLASS HANDLE—Impervious to moisture. • Stronger to withstand rough usage. • Ribs for firm grip and minimum hand contact area. • Handle material same as insulators.

COOL OPERATION—Solid copper CADWELD connection—no resistance heating.

LIGHT WEIGHT—14 oz. suitable for *continuous* 3/16" and under electrodes—intermittent 1/4" usage.

CADDY®
ARC WELDING ACCESSORY DIV.
ERICO PRODUCTS, INC.
2070 E. 61st PLACE • CLEVELAND 3, OHIO

WRITE TODAY FOR NEW 1955 CADDY CATALOG

New Tempilstiks°

Tempilstiks° for 463° and 488° F which have been under development for some time are now available.

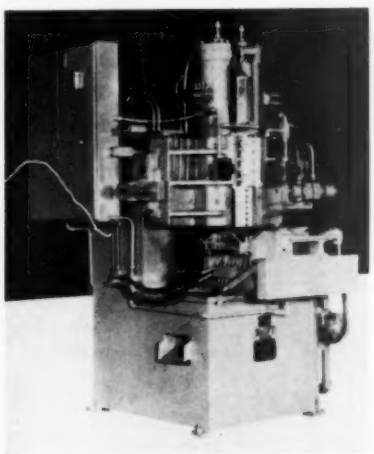
These new intermediate temperature ratings supplement the 413° and 438° F Tempilstiks° which were announced about two months ago. Tempilstiks° are now available in 12½° F intervals from 113° to 500° F, in 25° steps from 500° to 550° F, and in 50° F increments from 550° to 2000° F.

Samples available on request, Tempil° Corp., 132 West 22nd St., New York 11, N. Y.

Flash Welder

Swift Electric Welder Co., Detroit manufacturer of flash-welding equipment, has announced a special two-machine process for the welding and trimming of transmission bands, which involves the joining of bands to forgings.

The welding machine welds the band to the forging while a vertical broaching machine alongside performs the trimming operation.

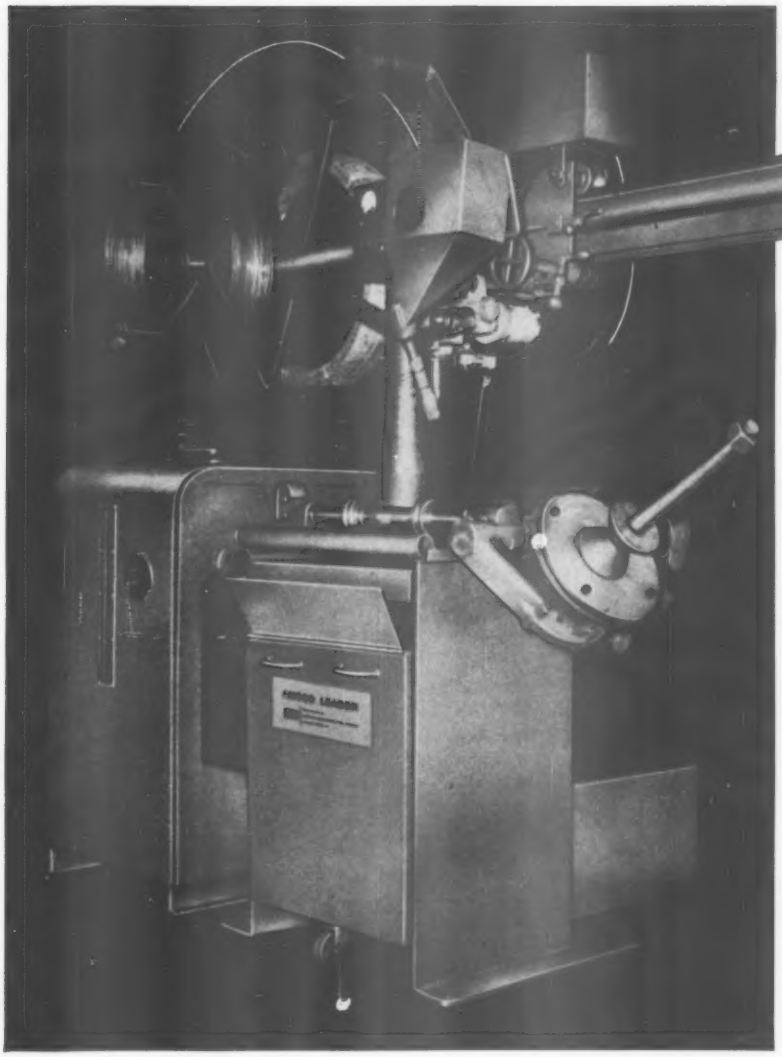


Powered by a 75-kva transformer, this new welder features a motor-driven cam for push-up, air-operated clamps, and sequentially geared automatic flash and upset.

The vertical broaching machine is hydraulically operated with self-contained hydraulic system, and hardened and ground wear plates. The multitooth broach trims the part practically to gage, or it can be set to undercut. To prolong tool life flash is removed while the metal is still hot.

In the welding of transmission bands (approximately 2 x 1/8-in.) to a forging in two places, a production line of two welders and two trimmers is commonly employed. The first weld is made and trimmed, and then the second weld made and trimmed.

While these machines have been es-



Here are facts about the great, new Amsco® Leader automatic electric welder

The Amsco Leader is a complete electric welding unit in one package. It is designed to combine all the essential needs of job shop operation, production manufacturing and automatic hardfacing in a single, efficient machine.

Easy handling of cylindrical, conical and flat work is made possible by a versatile, horizontal positioner.

It is equipped with an automatic welding head and operator's control panel. In addition, these outstanding design features are built into Amsco Leader machines: horizontal arm with power lift; cam-actuated, visible-feed flux hopper; two-piece, adjustable, caster-mounted flux bin; automatic, self-adjusting Hi-frequency Arc Starter and heavy-duty, worm-driven positioner.

When you purchase an Amsco Leader, trained personnel will supervise installation and train your operators. They will also consult with you on production techniques whereby you may realize the greatest potential from this fine automatic electric welder. For additional information, contact your local Amsco Distributor.

Brake Shoe

AMERICAN MANGANESE STEEL DIVISION
Chicago Heights, Ill.

Here are the

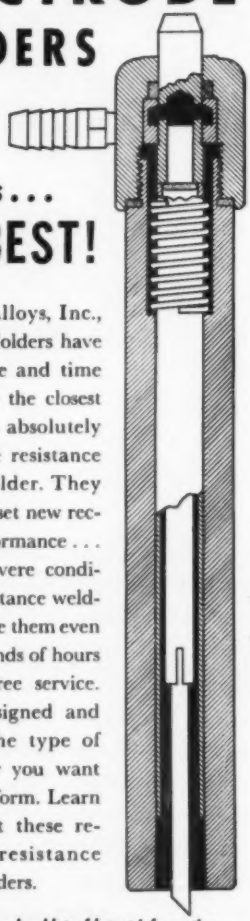
7 "MUSTS"

in selecting

RESISTANCE WELDING HOLDERS

1 Leak-proof, positive Water Flow
2 High Conductivity
3 Simplicity of Design
4 Simple Maintenance
5 100% Rust-Proof Construction
6 Rugged . . . Long-Lived
7 Non-Magnetic Throughout

Specify WW® ELECTRODE HOLDERS on all counts... THE BEST!



Yes, WW Alloys, Inc., Electrode Holders have proved time and time again to be the closest thing to an absolutely trouble-free resistance welding holder. They continue to set new records of performance . . . the most severe conditions in resistance welding don't faze them even after thousands of hours of trouble-free service. They're designed and built for the type of rugged duty you want them to perform. Learn more about these remarkable resistance welding holders.

Send for free booklet of latest information on Resistance Welding.

WW ALLOYS, INC.

42804A

Division of Fansteel Metallurgical Corporation
11644 Cloverdale Ave. • Detroit 4, Michigan

pecially developed for bands used in automatic transmissions, they are also adaptable for many other applications involving rings, tubes and similar joining operations.

Further information can be obtained on these new machines from Swift Electric Welder Co., 8095 Livernois, Detroit 4, Mich.

Welding Die-Cast Alloys

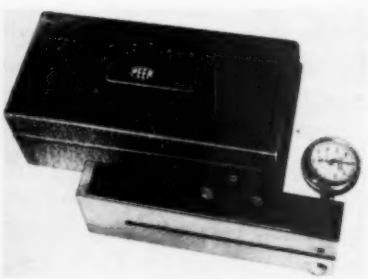
Oxweld No. 49 Rod, an extruded white metal rod for low-temperature oxy-acetylene welding of die castings, has been made available by Linde Air Products Co., a Division of Union Carbide and Carbon Corp.

Oxweld No. 49 Rod flows smoothly and fuses readily without flux or excessive puddling. Welds made with it in zinc-base alloys (about three-fourths of all die castings are of this type) are clean and uniform, and have greater strength than the original cast metal. Satisfactory welds with this new rod also can be made in most aluminum- and magnesium-base die-cast alloys.

Included with each package are easy-to-follow instructions for welding die-castings such as those used in paint sprayers, fuel pumps, vacuum cleaners, coal stokers, carburetors, motor and gear housings, portable tools and the like.

Spot Welder Tip Force Gage

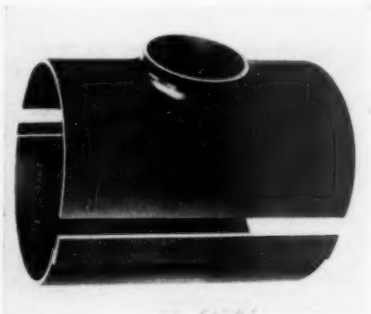
Peer, Inc., manufacturers of resistance welding machines and electronics equipment, announce a low-cost ($75.00) gage for accurately measuring electrode force on spot welders. Capacity of the dual range instrument is up to 3000 lb in increments of 10 lb. The gage is supplied in a cork-lined, steel carrying case with a black wrinkle finish.



The gage fills a need for a moderately priced instrument to measure or adjust tip force on resistance welders. Since tip force is one of the principal variables (current, time, tip size and tip force) which must be controlled for satisfactory welding, the gage is useful in setting up welding schedules, adjusting or checking machines, quality control, measuring ram friction, etc. The gage is simple and strong enough for everyday use by the operator or other non-technical personnel, but capable of the accuracy required by development and research projects. It may also be used as a dynamometer to measure other forces such as drill pressures. Direct inquiries to: A. White, Peer, Inc., Box 697, Benton Harbor, Mich.

"Hot Taps" Are Made Stronger

A recently developed Tube-Turn Full Encirclement Saddle represents a marked improvement over the conventional saddles employed in the "hot tapping" of petroleum piping, when branch connections are to be installed. It is manufactured by Tube Turns, Louisville, Ky.



Tube-Turn Full Encirclement Saddle, with longitudinal strap welded to bottom half

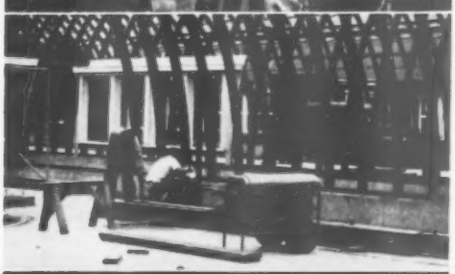
The research program entailed the use of the first pressure pulsating equipment ever built exclusively for evaluating welding fittings. The pulsation tests approximated the variations in pressures usually found in cross country service, and they give petroleum engineers the most accurate yardstick yet devised for judging the relative merits of welded branch connections reinforced in various ways, and tees.

The Tube-Turn Full Encirclement Saddle provides the 360° reinforcement so desirable when dealing with high pressures and large diam pipe and taps. It fully meets all requirements for reinforcement of welded branch connections as developed by Section 8 of the Code for Pressure Piping. When used with high yield strength pipe, the elimination of welding between the reinforcing member and the run pipe precludes the possibility of failure due to underbead cracking or to local stress concentration such as exists at the attachment weld to a conventional saddle.

The Tube-Turn Full Encirclement Saddle is designed for use with either high yield strength thin wall pipe, Grade B 35,000 or 42,000 yield strength pipe, and also for use with heavy wall cylinders employed for suction and discharge headers, bottles and pulsation dampers in compressor stations. It is available in standard and special sizes through 42 in., and in all straight and standard reducing outlet

MORE WELDING AT LOWER COST

with Sureweld® Portable D-C Arc Welder



The Sureweld Portable Gas-Driven D-C Arc Welder is truly an amazing welder. Amazing because it is so small and light and portable. Amazing because it can get in where other welders cannot go. Amazing because you can do far more jobs *faster* with it than any other welder of its capacity.

One man can move it. Two men can lift it. Any auto, truck or station wagon can stow it. On the job it produces welding power at once and it handles 85-90% of all on-the-job welding. Most amazing of all, it saves so much, it repays its cost several times a year.

On multi-story building the Sureweld Portable moves easily from floor to floor with the operator — always within standard cable length of the work. No extra cable to buy. No power wasted because of excessive cable length. No hoisting of heavy cable from floor to floor.

In pipeline operations, the operator moves it as his work progresses —and thus his work progresses *fast!* In plant repairs, the Sureweld Portable is on the job in a jiffy and through with the job — in a jiffy. No shutdown of plant processes in order to tie a motor-generator set into a power line.

In these and many other ways Sureweld Portable increases production and saves its cost over and over again. Its price to you may cause you to revise your budget considerably. Users say they don't know how they got along without this most useful and economical piece of equipment.

Let us demonstrate the Sureweld Portable — any place you say. No cost or obligation. Use the coupon below or contact your nearest NCG branch or NCG authorized dealer.

NATIONAL CYLINDER GAS COMPANY

840 N. Michigan Ave., Chicago 11, Ill.

Branches and Dealers from Coast to Coast

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J

NATIONAL CYLINDER GAS COMPANY
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☐ Please rush Illustrated Bulletin NH-121 containing full details of the SUREWELD Gas-Driven D-C Arc Welder.

☐ You may arrange, at no obligation to me, a demonstration of the Sureweld.

NAME_____ POSITION_____

FIRM_____

ADDRESS_____

CITY_____ ZONE____ STATE_____

sizes. The saddle is made from rolled plate of the proper chemical composition, mechanical properties and wall thicknesses required for the service conditions encountered. The saddle outlet is forged, and its I.D. corresponds to the O.D. of the branch outlet.

The Tube-Turn Full Encirclement Saddle is split longitudinally, on a horizontal plane, perpendicular to the axis of the outlet, thus eliminating welds in the critical crotch area. When clamped to the pipe, the two halves of the saddle are joined firmly by longitudinal straps. If the straps are shop welded to the bottom half of the saddle, only one field weld on each side is necessary in addition to the weld between the outlet of the saddle and the branch outlet. These are the progressive steps in making a field installation:

1. Install branch outlet.
2. Position and block up bottom half of saddle.
3. Slip top half of saddle over branch outlet. Bring the two halves together by means of a chain type pull up clamp or similar device.
4. Tack weld longitudinal straps securely to both halves of saddle and remove clamp.
5. Complete welding of straps.
6. Fillet weld the saddle outlet to the branch pipe.
7. Join the branch pipe to a Tube-Turn welding neck flange and prepare to tap.

When applying a Tube-Turn Full Encirclement Saddle to compressor station bottles, dampners, etc., where heavier wall thicknesses are customarily used and materials are free from underbead cracking potentialities, the straps can be omitted and the halves welded to the run and to each other. The ends may be fillet welded circumferentially to the run to give a more finished appearance.

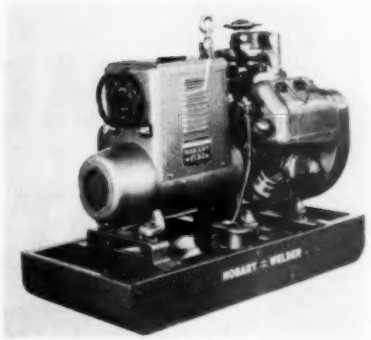
Tube Turns is a division of the National Cylinder Gas Co., Chicago.

New Hobart 250-Amp DC Welder

With the addition to their line of a new low cost 250-amp d-c arc welder with a 4-cylinder air cooled engine, Hobart Brothers Co. now offers a choice of liquid or air cooled engine driven 250-amp welders.

The generator of this new 250-amp arc welder is the multi-range type, with slight modifications to provide less bulk, lighter weight, and low cost in equipment where such factors are more important than some of the less essential conveniences provided in the larger Hobart models. It is directly connected to an economical operating, air cooled, industrial type Wisconsin Model VF4 engine.

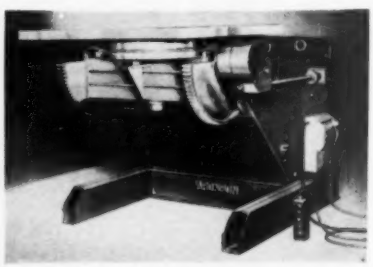
A convenient control panel is located at the generator end of the unit. On this are mounted the large range wheel, volt amp adjuster knob, reinforced bus bar type cable terminals, and power outlet receptacles, as well as the starter button for a battery equipped unit. Engine choke, hand throttle and magneto switch (on magneto equipped unit) are all located at the engine end for convenience in starting.



On this particular model a power outlet receptable is provided, for use only when the unit is not being used for welding. It is connected to the welding terminals and its output is 2 kw dc at 70-v. Operates lights and universal tools when the unit is not used as a welder. For complete information, write Hobart Brothers Co., Dept. 205-h, Troy, Ohio.

Gear Driven Positioners

Aronson Machine Co., Arcade, N. Y., manufacturers of welding positioners announces the introduction into their line of precision gear driven positioners, their new Models HD160 and HD240 Gear Driven Positioners. The most common application of these Positioners is for positioning heavy weldments to obtain better welds in the downhand position. The manufacturer has followed their basic design principle of providing the box-type chassis so that all motors and electricals are enclosed within the chassis to prevent damage by falling objects, flux and weld spatter. The table rotation gears are totally enclosed and packed with grease at the factory providing lifetime minimum backlash. The HD160 Positioner is capable of supporting 16,000 lb at 12-in. Center of Gravity with table rotation at Zero to 0.64 rpm and is standard with Magnetic Braking. The table tilts 135° in 46 sec with full load.

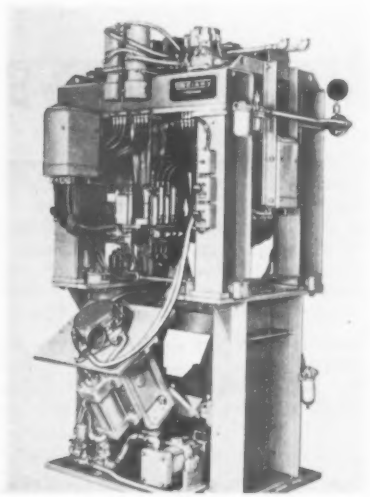


3 good reasons why...
MANGANAL
U.S. PATS. 1,876,738—1,947,167—2,021,945
11%-13½% Manganese-Nickel Steel
HOT ROLLED PLATES
last much longer than new
TRUCK BOTTOMS
• WANT PROOF? Try them on the next truck bottom job
• WANT DETAILS? We'll be glad to send them to you
1. They're TOUGH!
2. They're DURABLE!
3. They WORKHARDEN!
STULZ-SICKLES CO.
SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.
NEAREST DISTRIBUTOR UPON REQUEST

The HD240 Positioner will support 24,000 lb at 12-in. center of gravity with table rotation from Zero to 0.64 rpm and is standard with Magnetic Braking. The table tilts in 46 seconds with full load. Precision Limit Switches and Magnetic Braking on the tilt movement provide smooth safe stops of heavy weldments. All drives are direct coupled; there are no belts. All bearings are anti-friction and are packed for lifetime operation. Adjustable base with six table heights are standard on both positioners from minimum of 59 in. to maximum of 95 in. T-slot tables provide 54 × 54 in. clamping area and are furnished with four $^1/_8$ in. nuts for holding fixtures. All controls are on 110 v safety control circuit. Ground conduction is guaranteed at 2000 amps by the manufacturer, and ground blocks for easy attachment of ground cable are provided on the chassis of each positioner. Positioners are easily adapted to constant speed and/or fixed based operation. The rotation torque is increased 50% when the table rotation is at 0.35 rpm or lower on both models.

Multiple Electrode Machine

Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., Bulletin No. 313-12 covering the Sciaky SX 36 G, the new Sciaky Standard Multiple Electrode Machine for high production resistance welding applications.



A Sciaky Standard Machine, the SX 36 G consists of a universal multiple gun base with two separate platen units. The platen units, operating independently, load in extended position—swing-in and lift to the welding position—and after the welding sequence is completed, retract and swing-out for unloading.

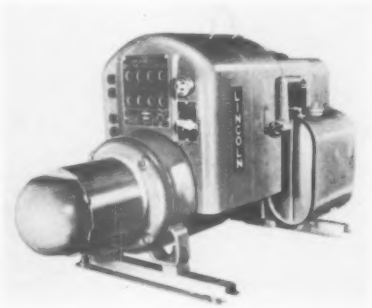
The platen lift and retraction feature permits multiple spot welding of deep drawn sections. The swinging in-and-out facilitates loading and unloading.

The SX 36 G is another notable Sciaky achievement in the design of electric resistance welding machines.

For more complete information about the Sciaky SX 36 G write for Bulletin No. 313-12.

Lincoln Weldanpower

A new combination welder and auxiliary or standby power uni. for maintenance work in building, construction, business and industry features low cost, large capacity and simultaneous output of both welding and auxiliary current. The Weldanpower machine, developed by The Lincoln Electric Co. of Cleveland, Ohio, is rated as a 200 amp welder and a 4 kva continuous duty power unit. For intermittent standby power, it is rated at 5 kva.



For business and industrial use the machine supplies a wide range of a c current for maintenance welding to repair equipment breakdowns, repair worn parts, hardface machine parts to resist wear, make replacement parts, build special equipment, fabricate bins, containers, conveyors, fences, piping, ladders, etc. The machine also supplies 230/115 v, 60 cycle single phase a c standby power to operate grinders, drills, power tools, pumps, saws and lights.

The unit is expected to be useful in manufacturing plants to eliminate stringing power supply lines for making on-the-spot repairs. Contractors can use it for power tool operation, emergency lighting and general maintenance welding. Similarly it can be used by job shops, air conditioning and refrigeration contractors, plumbers, sheet metal contractors, farm implement dealers, municipal street departments, truck fleet operators, well drillers, hotels, hospitals, trailer parks and motels. Farmers can use it for emergency or auxiliary power and for farm welding.

For welding, the operating panel provides taps which supply a c current for use with electrodes ranging from $^5/_{64}$ to $^3/_{16}$ in. diam. In addition to the tap range of output, a heat control is used to raise or lower the current from any one tap to suit exact requirements of the welding job. A continuous current range from 20 to 200 amp is thus provided for welding, hardfacing brazing, heating and soldering. For auxiliary power, the panel provides a 230 v outlet accommodating a standard 3 prong plug and four outlets for 115 v power which accommodate standard 2 prong flat blade plugs.

Preventive Maintenance Inspection

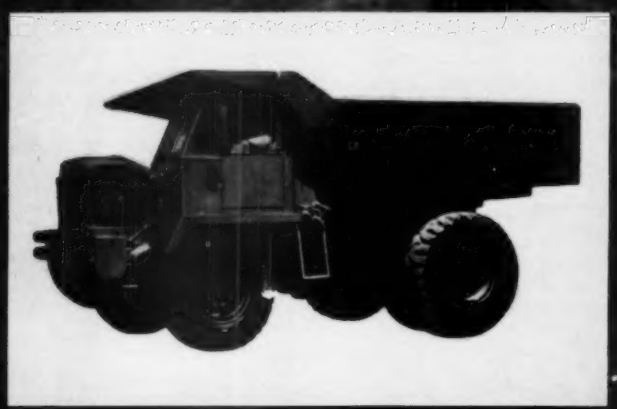
An entirely different magnetic particle inspection kit announced by Magnaflux Corp. of Chicago, offers light weight, portability and low cost. It is designed especially for preventive maintenance inspection, for weld inspection, and for limited volume inspection of any magnetic part wherever surface cracks are suspected. This use is very pertinent to salvage operations. The Y-5 yoke kit gives the full reliability of inspection by Magnaflux.

The Magnaflux Y-5 Yoke Kit comes in a metal carrying case, about the size of a fishing box, and weighs less than 30 pounds, complete. The Yoke itself is the magnetizing and testing instrument and weighs only 7 pounds. Magnaflux powder, powder bulbs, and operating instructions complete the kit. The Yoke is equipped with a 100-ft cord. It draws only 6 amp from any 110 v a c line.

The Magnaflux Yoke is particularly suited to rapid inspection for the surface cracks which are typical of fatigue. It will find any surface cracks caused in service. Because it uses a c magnetization, no confusing sub-surface indications will be developed.

Industrial plants and mill- will find the Magnaflux Yoke valuable for preventive maintenance inspection. Travelling cranes, crane hooks, press frames, lift truck forks, ladles, parts of heavy conveyors, shafts and many structural items can be quickly inspected in this way. The chemical and petroleum industries will find considerable use for the Yoke for checking pump parts, valve bodies, welds, etc. In new welds such surface defects or shrink cracks can be found. The Y-5 Kit is also extremely economical for inspecting parts of construction equipment in the field, such as booms, winch parts, hooks,

WELDING ARCS NEWS



BY SWITCHING FROM CONVENTIONAL E6012 ELECTRODES TO G-E STRIKEASY 1 IN WELDING FRAMES FOR 20-TON END DUMP TRUCKS

WELDING FOREMAN FOR DART TRUCK CO. SAYS:

"Speed?—G-E Strikeasy 1 electrode saves us

"Not only does General Electric's Strikeasy 1 electrode give us tremendous savings . . . it offers an operating ease that my men and I have never experienced in all our years in welding."

This is the conclusion reached by Mr. E.A. Gassman, Welding Foreman for the Dart Truck Co., Kansas City, Mo.—manufacturers of the largest dump trucks in the world.

DART SAVED OVER 2 MAN-DAYS PER TRUCK, when it switched to the G-E Strikeasy 1 electrode for the welding of frames for its Model 20-S 20-ton end dump trucks. Dart says that this represents a 50% decrease in welding time over the conventional E6012 electrodes which were formerly used.

Such high speeds are realized because Strikeasy 1 uses a nonconductive rutile type coating enriched with powdered metal. When an arc is struck, the metal particles melt off to form part of the bead.

STRIKEASY 1 ELECTRODE IS EASY TO USE. A contact-type electrode, it forms a finely rippled bead when you simply drag it over the job. And less skill is required to hold arc length.

Also, slag practically peels off Strikeasy 1 welds without excessive chipping and cleaning. All this means that Strikeasy 1 helps cut down on operator fatigue—slashes training time for new operators.

IMPROVE YOUR COMPETITIVE POSITION, and cut labor and overhead costs by using Strikeasy 1 to speed up those applications where you are now using

General Electric Balanced Electrode Design Gives Better Over-all Results

Within any given electrode class, G-E electrodes give your welding applications a balanced combination of speed, weld-quality, and ease of use—for better over-all results. Application tested, "balanced design" is part of the entire G-E line of electrodes—the most complete line in industry.

"QUALITY WELDS" was the order for this Dallas skyscraper. G-E W610A electrode provided necessary fast strength welding.

BALANCED DESIGN pays off as G-E type W2308 stainless-steel electrodes are used in out-of-position welding this large cone.

(SEE INSET), DART TRUCK SAVES OVER TWO MAN-DAYS PER TRUCK. SEE STORY BELOW.

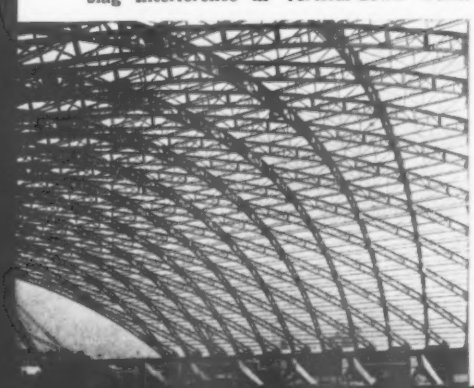
over 2 man-days per truck!"

conventional E6012 class electrodes.

Check your G-E welding distributor's name at the right and in the yellow pages of your phone book; ask him for: GEC-1231—Bulletin on Strikeasy 1; GEL-1196—Wall Chart for Selecting Stainless-steel Electrodes; GED-1634—Electrode Catalog, a pocket-size guide to electrode selection and application. General Electric Company, Schenectady, New York. 710-19

GENERAL ELECTRIC

PREFABRICATED ROOF is all-welded with G-E W612A, which reduces pinholing, slag interference in vertical-down work.



RUGGED EARTHMOVERS for tough mountainous duty are repair-welded crack-free with G-E W1016A low-hydrogen electrodes.

Contact Your G-E Welding Distributor Today

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Company

Florida: Hollywood—Florida Gas & Chemical

Georgia: Athens—Welding Gas Products; Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies; Gainesville—Welding Gas Products

Idaho: Boise—Gate City Steel

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—PerryWelding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Wichita—Standard Products

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equipment

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Oklahoma City—Hooper Supply; Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—H. & W. Welding Supply; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—McGinnis Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Wyoming: Cody, Lovell—Valley Motor Supply Co.

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

parts of automotive equipment, and many others.

One man performs the inspection by himself. He handles the Yoke with one hand, both power control and positioning, and with the other he dusts on the Magnaflux powder. The area covered by each application of the Yoke varies up to approximately 24 sq in., and the Yoke is so light and easily positioned that large areas, many parts, or many feed of welds can be inspected per man hour. The Yoke is easy to use in even restricted areas, and its 100 ft input cord permits very flexible operation.

The Y-5 Yoke Kit is available from Magnaflux Corp., 7300 West Lawrence Ave., Chicago 31, Ill. for only $185.00 (fob Chicago plant).

Electrode for High Nickel Alloys

An unusually versatile electrode for joining nickel and nickel containing alloys, trade named NiTectic 222 (patent pending) has been developed by Eutectic Welding Alloys Corp., Flushing, N. Y. Extensive field tests have indicated it is the long awaited answer to the problem of joining dissimilar high nickel alloys. It is excellent for joining austenitic stainless steel to nickel or to inconel, cast alloys to steel etc., and is believed to be the only electrode available for such purposes, states the manufacturer.

The difficulty of determining the exact analysis of nickel alloys when repairs are necessary, has been responsible for many failures. The new electrode will fabricate and repair such metals irrespective of their compositions. Exceptional weldability in all positions is claimed with unusally quiet transfer and lack of spatter. An extremely short arc can be maintained without danger of freezing and the almost 100% slag coverage can be removed with a slight impact.

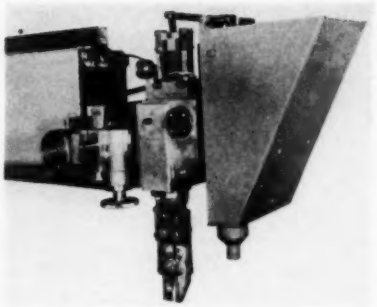
Further information may be had by writing to Eutectic Welding Alloys Corp., 40-40 172 St., Flushing 58, N. Y.

Automatic Head Mount

A bothersome problem, to users of automatic welding processes, has been the matter of positioning the welding head for a variety of operations. Failure to solve this has placed otherwise unwarranted limitations on the versatility and productivity of such equipment.

A general requirement in installation of automatic welding equipment is the lateral movement of the welding head or electrode across the seam. Other work requires angluar positioning of the head, either right or left, particularly for fillet welding.

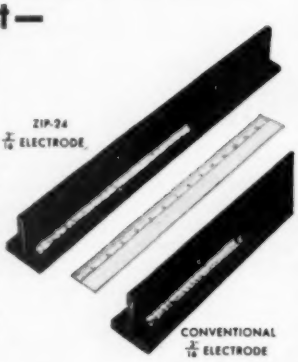
Some operations call for pointing or



leading the filler wire ahead of the normal downward position; others a backward inclination of the filler wire; and still others demand stationary positioning the head at 90° to the normal longitudinal travel to make circumferential welds on tanks, boilers, condensers and other cylindrical objects.

The Peck Uneek Head Mount, shown in the accompanying illustration, eliminates this problem, since the manufacturer claims all of these long needed and desirable adjustments are embodied in this attachment. This device is available for use with all standard welding heads and is easily mounted on any welding fixture. Manufactured by Cecil C. Peck Co., builders of quality automatic machinery for all welding processes, 4614 Prospect Ave. Cleveland 3, Ohio.

New Westinghouse ZIP-24 Electrode welds twice as fast— better, easier, too



FASTER WELDS—*50 to 70%* greater deposit rate. And an increase of *30 to 50%* in footage of fillet or lap weld per minute.
BETTER WELDS—balanced fillets give appearance of "machined finish" . . . no undercut with fillet and lap welds . . . perfect wall washup . . . easier slag removal . . . minimum spatter loss that reduces cleaning time.
EASIER WELDS—even-edged, smooth, finely rippled weld beads even when handled by an inexperienced operator. Ideal for "drag" technique.
IMMEDIATE DELIVERY—made possible with opening of our second electrode plant . . . a brand-new Westinghouse Electrode Plant at Montevallo, Alabama. To learn more about the remarkable new ZIP-24 just use coupon below.
J-21861

YOU CAN BE SURE...IF IT'S Westinghouse

☐ I would like free samples of the new ZIP-24 electrode.

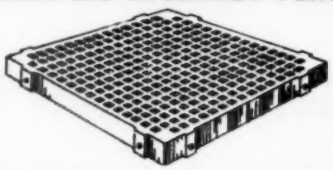
☐ Send me literature on the complete line of quality electrodes made by Westinghouse (B-6070).

WESTINGHOUSE ELECTRIC CORPORATION
Welding Department
P. O. Box 868, Pittsburgh 30, Pa.

Please send me a free copy of your folder on the ZIP-24 electrode (B-6389).

Name_____
Company_____
Address_____
City_____ State_____

WELDING and ASSEMBLY PLATENS



Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks— blacksmith blocks. 5′x5′ — 6′x6′ — 6′x8′ — 6′x10′ — 5′x10′ — 6′x12′ — 3′x3′ — either 6″ or 7″ thick.

STAHL EQUIPMENT CO.
94 Washington St., Brookline Village 46, Mass.

UNITED STATES TESTING COMPANY, INC.

INSPECTION and TESTING of
Welding and Weldments
QUALIFICATION of
Procedures and Operators

Main Laboratories **Hoboken, N. J.**

Boston - Chicago - New York - Philadelphia - Providence

a Original die after forging 3100 pieces

b same die after Rexwelding and forging 9300 pieces

CRUCIBLE REXWELD hard surfacing rods increased forging die life OVER 400%

for R. G. LeTourneau, Inc.

By Rexwelding, R. G. LeTourneau, Inc., Longview, Texas, increased the life of its production dies over 400%. The dies shown, for example, used to forge a plug adapter of SAE 1030 steel at 2350 F, had to be removed from the press after forging 3100 pieces because of excessive wear and heat checking. The same die, after worn areas were machined out and faces built up with Rexweld-A hard surfacing rod, produced 9300 pieces.

You can do the same in your shop. You'll find that Rexwelded dies have higher edge strength at elevated temperatures, and resist chipping, deformation and heat checking better. And parts can be Rexwelded over and over.

So, use Rexweld Rods on your next hard surfacing application. They are available in both bare rods and low hydrogen coated electrodes, in a wide range of grades and sizes. Call your local Crucible representative — he can provide a grade of Rexweld adapted to your specific job.

CRUCIBLE first name in special purpose steels

54 years of Fine steelmaking

REXWELD HARD SURFACING ROD

CRUCIBLE STEEL COMPANY OF AMERICA, GENERAL SALES OFFICES, OLIVER BUILDING, PITTSBURGH, PA.

REX HIGH SPEED • TOOL • ..EZISTAL STAINLESS • ALLOY • MAX-EL • SPECIAL PURPOSE STEELS

SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Section News

Informal Meeting

Columbus, Ohio—Dr. R. C. McMaster [AWS], of Battelle Memorial Institute, was the guest speaker at the May 14th meeting of the *Columbus* Section, held at the Broad Street Christian Church. Dr. McMaster gave a very informative as well as entertaining talk on his hobby "The Weather." His talk was followed by a film on the "High Lights of Big Ten Football" with running commentary and analysis of future prospects by Backfield Coach Eugene Fekete of the OSU Coaching Staff.

Annual Ladies' Night

Columbus, Ohio.—The ladies were invited to dinner and dancing at Holiday Hill, Delaware, Ohio on June 12th for the annual Ladies Night activities of the *Columbus* Section.

Family style dinner, served out-of-doors, was followed by dancing, square and social, also on the patio. More than 100 members and guests attended. Other activities included boating, ping-pong, games, cards and volley ball.

Business Meeting

Dallas, Tex.—The business meeting and stag party of the *Dallas* Section was held on May 26th at the River Valley Country Club with an attendance of 58 at the dinner and meeting.

Announcement was made of the new officers elected for the 1954–55 season. Refreshments, dinner and entertainment followed.

Heliarc Welding

Austin, Texas.—The technical portion of the July 23rd meeting of the *Austin* Division of the Houston Section consisted of a lecture and demonstration on "Heliarc" Welding by Linde Air Products Co. personnel.

Announcement was made at this meeting of officers for 1954–55 season as listed under "New Officers of Sections."

Final Monthly Meeting

Long Beach, Calif.—The final monthly meeting of the 1953–54 season was held on June 18 by the *Long Beach* Section. Following the introduction of new officers for the 1954–55 season, Bill Stroppe, undisputed king of the Sports Car Racing Fraternity, gave an interesting talk on his favorite subject "Auto Racing." Several speed films were shown in conjunction with Mr. Stroppe's talk.

Nondestructive Testing

Kansas City, Mo.—The *Kansas City* Section held its monthly dinner meeting in Fred Harvey's Pine Room on May 13th. Thirty-two persons were present for this final meeting of the season.

The speaker for the evening was Lloyd Oye, of the Magnaflux Corp. Since his graduation from the University of Minnesota 11 years ago Mr. Oye has been with Magnaflux serving as welding engineer, field engineer, West Coast Manager, and is now assistant Sales Manager. Mr. Oye gave an excellent talk entitled "Non-Destructive Testing as an Aid to Increased Use of Welding." He gave a very understandable description of the Magnaflux Process. He went further to discuss the economics involved in testing welds with Magnaflux. He used slides with his talk showing the testing of welds in the field using both portable and stationary equipment.

All Welded Penstock

Long Beach, Calif.—An excellent full color and sound film entitled "More Power to Rio," describing an all welded penstock with a water head of 1100 feet and giving a detailed description of the welding procedure used and the construction employed, was shown by J. J. Chyle [AWS], Director of Welding Research, A. O. Smith Corp., at the May 21st dinner meeting of the *Long Beach* Section held at Millers Restaurant.

Atomic Power Developments

Salt Lake City, Utah—The regular monthly dinner meeting of the *Salt Lake City* Section was held on May 20th at the Hotel Temple Square. Dr. Lyle Borst, Professor of Physics at the University of Utah, gave an excellent non-technical talk on "Post War Developments of Atomic Power."

Spring Party

Salt Lake City, Utah.—Eighty members and guests of the *Salt Lake City* Section attended the Spring Party on June 19th at the Whitmore Oxygen Lodge, Little Cottonwood Canyon.

Early Welding Developments

Tucson, Ariz.—The *Tucson* Section held their regular monthly dinner meeting May 25th at 7:30 P.M. at the Tucson Municipal Golf Course club house with 28 members attending the dinner and meeting.

Arthur S. Mann, Pima County Industrial Engineer, was the guest speaker. Mr. Mann talked on the early developments of welding from a background of experience with the U. S. Army Engineers in World War 1 and the Paramount Textile Machinery Co. of Kankakee, Ill. of which he was manager for 14 years. He also outlined what the future industrial growth of Tucson should be.

Prior to Mr. Mann's talk, the election of Section officers for the coming year was held.

New Officers of Sections

Anthony Wayne

Chairman—Gerald Springer, Fort Wayne, Ind.
1st Vice-Chairman—D. B. Rice, Fort Wayne, Ind.
2nd Vice-Chairman—Jacob S. Geiser, Kendallville, Ind.
Secretary—Delbert Clark, Waterloo, Ind.
Treasurer—Delbert Clark, Waterloo, Ind.
Chairman, Membership Committee—Russel F. McNutt, Fort Wayne, Ind.
Chairman, Program Committee—Jacob S. Geiser, Kendallville, Ind.
Technical Representative—K. H. Zimmerman, Fort Wayne, Ind.

Magnetic? OR Electronic? WELDER CONTROL — WHICH WILL DO YOUR JOB BEST?

Square D makes them all... for simplest or most exacting applications!

Magnetic

for General Purpose Machines

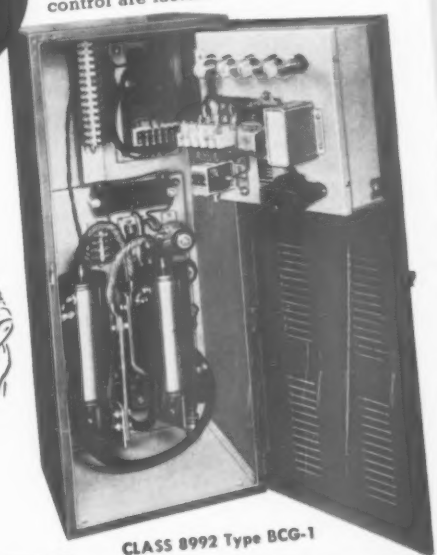
For applications requiring widely varying welding conditions, normal welding speeds and maximum simplicity.

CLASS 8992 Type BBG-1

Electronic

for High Speed Welding

For production line (gun or stationary) welders and other applications where high speed, high currents or dual gun control are factors.



CLASS 8992 Type BCG-1

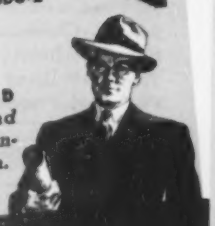
Electronic (SYNCHRONOUS)

for Precision Welding

For welding aluminum, other non-ferrous and ferrous metals requiring precision weld times; stepless heat control; slope or taper control.

CLASS 8993 Type BDG-2

You'll find your nearby **Square D Field Engineer** *a source of sound counsel in selecting the welder control best suited to your application.*



SQUARE D COMPANY

Arizona

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1st Vice-Chairman—William F. Fischer
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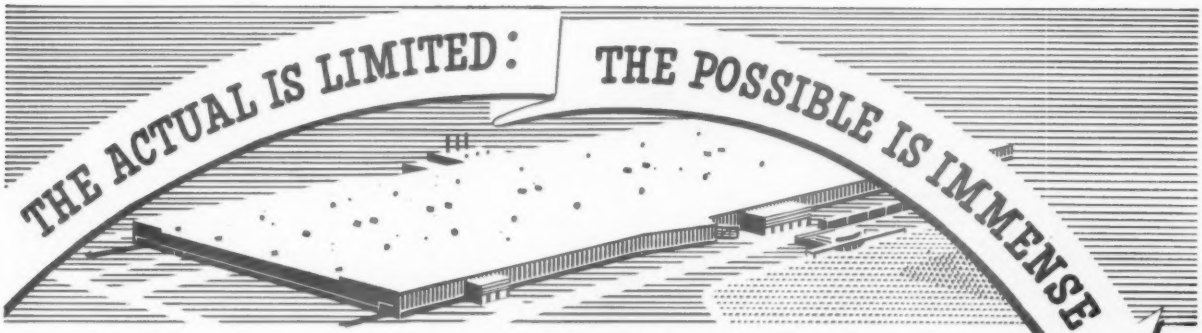

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★ Operates in *all* positions
★ Spatter is less
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★ Can be used with *any* AC or DC welder

TYPICAL APPLICATIONS:

DRAG CHAINS	PLOW POINTS	DRAGLINE BUCKETS
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SAVES INVENTORY. Why stock so many different hardsurfacing rods? Two Lincoln rods... new Abrasoweld and Faceweld handle almost all your hardsurfacing needs. And Lincoln delivers *more wear per dollar* to cut your hardsurfacing costs.

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Cuts hardsurfacing costs *on construction equipment like this dragline bucket. Teeth, lip, bottom and side plates are* ***built up*** *with long wearing Abrasoweld.*

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Some 60 members of the York-Central Pennsylvania Section witnessed the installation of officers and heard a panel discussion on welding at the meeting held in the Pine Tree Inn on May 26. Shown left to right are: Walter W. Lilly, Jr., panel chairman; William Delong, vice-chairman of the York Section; Paul L. Stumpf, chairman; Frank Logue, retiring chairman, and Charles Allen, treasurer.

LIST OF NEW MEMBERS

Effective June 30, 1954

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B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

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Senger, Edwin C. (B)

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Alm, Richard G. (C)
Skora, Joe (C)

CINCINNATI
Whalen, S. J. (C)

CLEVELAND
Figuli, Paul (C)
Gerdon, Harvey J. (B)
Seidorf, Christian (B)

COLUMBUS
Faulkner, Glenn E. (C)
Wilson, Daniel (D)

DAYTON
Keim, Raymond (C)
Mockbee, Randolph (B)

DETROIT
Falkowski, Frank G. (B)
Morgan, Stanley W. (B)

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Befort, John (C)
Grode, Phil E. (C)
Harrant, A. E. (B)
Hart, Eugene E. (B)
Holtz, H. C. (C)
Koch, Edgar (B)
Revelt, Jean J. (C)
Schabo, Earl W. (C)
Velden, George Vander (B)
White, Robert C. (C)
Winter, Walter W. (C)

HOUSTON
Bailey, LLoyd Jr. (B)
Cudd, J. G. (B)
Fore, Thomas A. (D)
Griffin, Bert, L. (C)
Smith, A. M. (B)

IOWA
Mayberry, W. R. (B)

KANSAS CITY
Fizzell, J. L. (B)
Willard, Wayne E. (B)

LONG BEACH
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Egge, Edward S. (C)
Long, Parks (C)
Pickle, Harold A. (C)
Rawling, Malcam W. (C)

LOS ANGELES
Bringer, Ralph A. (C)
Simmons, Alfred R. (C)
Simpson, Richard M. (C)

NEW JERSEY
Chamberlain, John B. (B)
Davis, Elliel W. (B)
Haas, Robert M. (C)
Lesnewich, A. (C)
Monnoleto, Louis (B)

NEW ORLEANS
Abaunza, Alfred E. (B)
Bach, Clayton C. (B)
Belle, Clay W. (B)
Bourgeois, Claude J. (B)
Borchers, Chas. W., Jr. (B)
Brown, Harvey B. (B)
Carney, Thomas C. (B)
Crawford, Borden M. (B)
Dodd, Mark G. (B)
Duclos, Louis (B)
Fatland, Theodore L. (B)
Francillo, Luigi (B)
Gaines, Earl B. (B)
Galatas, James E. (B)
Gallwey W. J. (B)
Gray, C. W. (B)
Herr, Richard D. (B)
Huffman, J. D. (B)
Johnson, Joseph B. (B)
Kemp, Clarence H. (B)
Kent, Julius W. (C)
Kitchen, Robert L. (B)
Lane, H. J. Jr., (B)
Lechler, William F. (B)
Massimini, W. A. (B)
Pichon, Jerome J. (B)
Ramirez, Adam J. (B)
Richoux, Woodrow J. (B)
Shirley, Louie Edwin (C)
Szczepanski, Henry A. (B)
Tallant, James W. (B)

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Barnes, Seymour (C)
De Hayes, Frank J. (B)
Hanna, Charles W. (B)
Hraba, Albert (B)
McDowell, David W., Jr. (B)
Stanfield, Charles (B)
Warren, Joseph J., Jr. (B)
Wolf, Oswald (C)

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Klein, Sheldon G. (B)
Persson, John A. (C)
Smith, Ray (C)

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Kafer, Elmer, Jr. (B)
Kruger, Stanley (B)
Sharrock, Roy (B)
Ulsh, Harold E. (B)

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Anderson, A. J. (C)
Bishop, J. O. (C)
Bobbit, Earl T. (C)
Chenault, Harvey L. (C)
Hall, C. W. (B)
Hallock, Roger W. (C)
Jenkins, John R. (C)
McDermott, Ralph E. (C)
Mundell, W. H. (C)
Northcott, J. B. (C)
Powell, C. L. (C)
Schaub, Paul (C)
Thorp, Lonnie Doyl (C)
Van Dame, Al (C)
Williams, J. A. (C)
Wornstaff, W. M. (C)
Wyrik, William (C)

OLEAN-BRADFORD
Cagliostri, Joseph H. (B)

PASCAGOULA
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PHILADELPHIA
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PITTSBURGH
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PUGET SOUND
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ROCHESTER
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Harrison, Richard G. (B)

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Montero, Joe (C)
Vargas Rivera, Hector (C)

SYRACUSE
St. Louis, Donald A. (C)

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McClure Chester B. (C)

TULSA
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Sullins, Delmer D. (B)

WESTERN MASS.
Mission, Arthur (B)

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George, Charles Herbert (B)
Mackillop, Victor J. (C)
Morrison, Ralph (B)
Noguchi, Kosaku (B)
Redmond, William T. (B)
Reynolds, Dan W. (C)
Truett, C. M. (C)

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abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,682,597—Welding Apparatus & Welding System—Ian Jack Pickering, Birmingham, England, assignor to General Electric Co., Ltd., London, England.

This patent is on apparatus for controlling the supply of welding current to an electrode and comprises a contactor for connecting and disconnecting the welding current supply, while a relay is present and is responsive to the current in the welding circuit and arranged to control the operation of the contactor. Other contacts are present for connecting a low voltage supply to the welding electrode when the welding supply is disconnected and such contacts are controlled by the relay. Other relay means are present and responsive to a flow of current in the low voltage supply circuit between the welding electrode and the work for operating the contactor to connect the welding current supply thereto.

2,682,598—Method of & Apparatus for Keeping Electric Arcs Alive for Repeated Welding Operations—Eugene W. Macoy, Old Greenwich, Conn., assignor to American Can Co., New York, a corporation of New Jersey.

Macoy's patent is on a specialized fusion welding method relating to welding seams of metal can bodies with an electric arc. The method comprises advancing the can bodies in spaced and processional order into and through a welding station and maintaining an electric arc alive while moving the arc continuously through an endless circuitous path of travel. Part of the path extends parallel with the seam of the can body at the welding station to weld the seam and the remainder of the path is remote from the seam and directed toward the starting point of the next following can body advancing into the station.

2,683,204—Circuits for Welding Semiconductor Devices—Jack F. Roach, Van Nuys, Calif., assignor, to Hughes Aircraft Co., a corporation of Delaware.

This patent is on a specialized circuit to produce an electrical weld first between the crystal and whisker elements of a first semiconductor device and then between the crystal and whisker elements of a second semiconductor device. The circuit includes specialized pulse forming network and weld current control means.

2,683,206—Welding Electrode Holder—Harry E. Day, Huntington Woods, and Edward G. Biederman, Detroit, Mich., assignors to Link Welder Corp., Detroit, Mich., a corporation of Michigan.

This electrode holder includes a mounting plate and means for connecting a cable thereto. A welding tip adapter of a generally elongated shape is present in the holder and the tip adapter has means at one end adapted to receive a welding electrode tip. Other means are provided for conducting a coolant to and from the electrode tip.

2,683,207—Stranded Welding Rod—Dartrey Lewis, Trenton, N. J., and Howard F. Stirn, Yardley, Pa., assignors to John A. Roebling's Sons Corp., Trenton, N. J., a corporation of Delaware.

Lewis' patent relates to a welding electrode including a sheath made from a plurality of helically formed wires and a wire core wholly within and coextensive with the sheath of wires. The sheath wires have compositions with lower melting points than the core wire which is of reduced size so that the sheath wires and the core wire will be consumed at a substantially equal rate.

2,683,790—Electrical Welding Apparatus—Durward Kenneth Hopkins, Peoria, Ill., assignor to Peoria Steel & Wire Co., Peoria, Ill., a corporation of Illinois.

In this patent, a welding transformer assembly is disclosed and comprises a

For Intermittent Service
You Can't Beat this Welder

You Can't Beat its Price

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New P&H TI-295 295-amp AC Welder

America's most complete line of arc-welding equipment and electrodes

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A full range of sizes up to 625 amps (NEMA-rated). All are connectable to 220 or 440 volts. Dial-lectric Instantaneous Remote Control is fingertip control — gives you any heat you want, right at the work.

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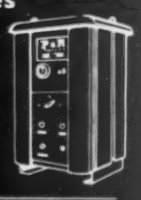

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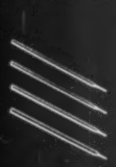

. . . the only low-cost intermittent-type welder that can handle low-hydrogen and stainless-steel electrodes

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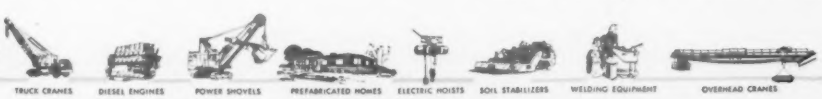

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frame of electrical conducting material having at least three legs insulated from each other at one side of the frame and connected at the other side of the frame. Primary windings are mounted in the spaces between the adjacent legs on the frame and connect, respectively, to different phases of a source of polyphase current. The frame forms a single turn secondary for the transformer. A plurality of conductor bars extend across one side of the frame and are electrically connected with the legs. A plurality of electrode-supporting members are mounted on the conductor bars and are electrically connected thereto.

2,683,791—Wire Arc Welding Method and Device—Herbert E. Ruehlemann and Wolfgang A. Menzel, Silver Spring, Md.

In this patent, a method of arc welding electrical circuit connections from an a-c power source is disclosed and covered. The method comprises the steps of positioning a first electrode of a welding circuit in electrical contact with a portion of the connection to be welded, advancing a second movable welding electrode into contact with the connection and initiating a welding arc. A controlled reinitiation of the welding arc is provided with cyclic extinguishing changes in the power source and a predetermined arc gap is established within limits of electrode movement with each re-establishment of the arc and such arc gap is controlled in correlation with the magnitude of arc current flowing. The arc is finally extinguished at the completion of the weld in correlation with fusion erosion of the connection beyond the predetermined limits of movement of the movable electrode.

2,684,421—Apparatus for Forming Terminals and Attaching Same to Wires—Roy P. Hipple, Warren, Ohio, assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This patent relates to specialized apparatus for forming a terminal clip from a metal strip. The apparatus includes dies and punches for shaping the terminal from a metal strip and electrode means for welding a terminal wire to the clip which is severed from the original metal strip prior to the welding action.

2,684,422—Chain Welding Machine—Paul Esser, Koln-Raderberg, Hans Stutzer, Koln-Bickendorf, and Alfred Gremm, Koln-Sulz, Germany, assignors to Meyer, Roth & Pastor, Koln-Raderberg, Germany.

Esser's patent is on a specialized machine for electric resistance butt welding of chain links.

2,684,423—Apparatus for Forming Terminals and Attaching Same to Wires—Roy P. Hipple, Warren, Ohio, assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

In this patent, more details are covered regarding the punch press and die means of the mechanism shown in and covered by Patent 2,684,421.

2,684,424—Roller Electrode Spot Welder—Charles N. Anderson, Renton, Wash., assignor to Boeing Airplane Co., Seattle, Wash., a corporation of Delaware.

A manual feed-spot welding machine is covered in the patent. This machine includes upper and lower roller electrodes and cyclically operated means for reciprocating at least one of the electrodes toward and from the other. Resilient means are interposed operatively between one of the electrodes and a support therefor and deflectable progressively in response to pressure applied thereto to establish progressively increasing electrode pressure on the work during movement of the electrode support toward the electrode. Normally released brake means cooperate with at least one of the electrodes to apply a rotation-braking action thereto automatically in response to a positioning of the cyclically operative means when applying maximum electrode pressure to the work.

2,684,425—Induction Brazing Jig—John C. Vickland, Wellsville, N. Y., assignor to Air Preheater Corp., New York, N. Y.

This jig is for a heat exchanger envelope including a pair of metallic plates provided on their outer surfaces with longitudinally extending metallic fins and spaced apart by longitudinally extending rows of sinuous wires. The apparatus also includes a plurality of parallel roller means spaced apart to provide a movable bed for the envelope assembly and an induction heating coil is parallel to the rollers and has an opening therethrough to allow passage of the envelope assembly when advanced over the roll. Means are provided for advancing the envelope assembly through the coil to subject it to the heat produced thereby.

2,684,426—Work Supporting Apparatus for Fusion Welding—Otis R. Carpenter, Barberton, and James C. Fesler, Alliance, Ohio, assignors to Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

This patent relates to a specialized machine for fusion welding two rows of studs to a tube. The apparatus includes a pair of electric welding heads movable along the tube and cooperating with a clamping plate used to hold the studs with the stud ends in alignment.

Bulletin 17

The Welding Research Council and the Ship Structure Committee have joined forces in publishing and making available to industry an interesting comprehensive report entitled:

A Critical Survey of Brittle Failure in Carbon-Plate Steel Structures Other Than Ships

by M. E. Shank

This report covers both riveted and welded failures and should form part of the library of anyone concerned in any way with the problem of brittle fractures.

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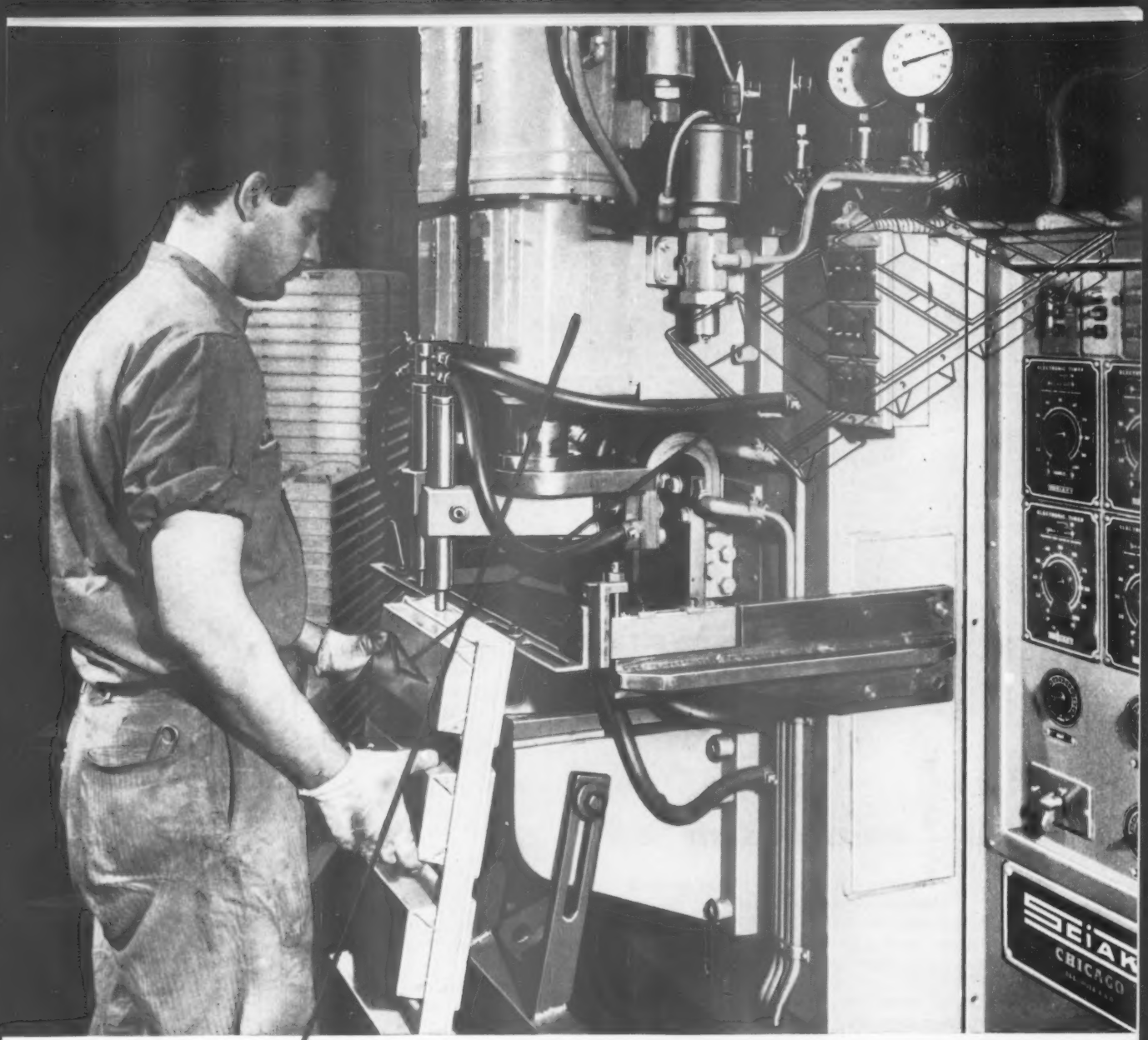

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The Lockwood Manufacturing Company, Cincinnati, Ohio, manufacture their aluminum bread pans with Sciaky Patented Three-Phase spot welded construction. Rapidly replacing conventional riveted aluminum pans, the spot welded aluminum pans are more durable, more sanitary, safer to handle, and bake a superior product. Further, the production ability and consistency of Sciaky Three-Phase welders reduces fabricating costs. As a result, more and more bakers are using aluminum pans and reaping the benefits of their light weight and long life. For complete details, write for "Resistance Welding at Work," Volume 3, — No. 10

The Three-Phase spot welding of aluminum bread pans at Lockwood is another fine example of Sciaky basic thinking — welders designed to do *more useful work* at *lowest operating cost* with *maximum reliability.*

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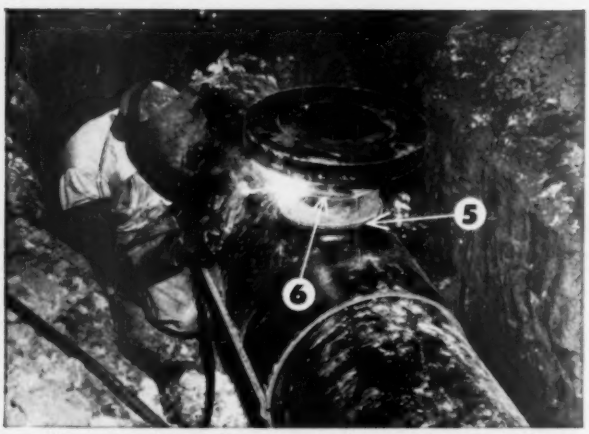
3. *Slip top half of full-encirclement saddle over branch outlet. Bring two halves together tightly by means of clamp such as shown.*

4. *Tack weld longitudinal lap plates to top half of saddle, remove clamp and complete welding of plates. (Plates are shop-welded to bottom half).*



5. *Fillet weld saddle outlet to branch pipe.* 6. *Join branch pipe to* TUBE-TURN *Welding Neck Flange. Normal tapping procedure follows.*

NOTE THAT when used with high yield strength, thin-wall pipe, as shown above, circumferential welds between saddle ends and run pipe are not required. This precludes possibility of failure due to underbead cracking or to local stress concentrations which exists at such attachment welds with conventional saddles or other types of "hot tap" fittings which must be fillet welded to high yield strength, thin-wall pipe. The TUBE-TURN Full-Encirclement Saddle fully meets all requirements for reinforcement of welded branch connections as developed by Section 8 of the Code for Pressure Piping.

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Supplement to the Welding Journal, September 1954

Applicability of Charpy Test Data

Fracture propagation is difficult in welded structures of rimmed and semikilled steels at temperatures which show 20 ft-lb Charpy V energy but higher values are indicated for fully killed steels

by P. P. Puzak, M. E. Schuster and W. S. Pellini

Abstract

Service data have demonstrated that the initiation of brittle fractures in welded structures of semikilled and rimmed structural steels is possible only at temperatures such that the steel develops less than 10 ft-lb energy in Charpy V tests. Similarly, propagation is possible only at temperatures of less than Charpy V 20 ft-lb. Crack-starter tests demonstrate that these steels have essentially no ductility in the presence of a sharp crack at temperatures below the Charpy V 10 ft-lb transition; this accounts for fracture initiation in service. Similarly, these tests demonstrate that fracture propagation changes from easy to difficult at temperatures of approximately 20 ft-lb Charpy V energy which is also in agreement with service.

Crack-starter tests of fully killed steels, for which no service experience is available, indicate that the critical fracture initiation and propagation temperatures are related to higher values of Charpy V energy. These data are interpreted to signify that service data correlation based on the NBS ship fracture steels cannot be extended to steels of different types.

INTRODUCTION

THE National Bureau of Standards investigation of the Charpy V energy transition characteristics of ship fracture steels[1] demonstrated that ship failures occurred at temperatures corresponding to the lower portion of the Charpy V energy curves. Plates in which fracture initiated were characterized by Charpy V energy of 11 ft-lb max at the fracture temperature while plates which permitted the propagation of fractures were characterized by Charpy V energy of 19 ft-lb max. This information suggested an approach to the problem of specification of steels for large welded structures based on the critical temperatures of Charpy V 10 and 20 ft-lb. Accordingly, it has been considered that fully killed ABS-C type steels which have Charpy V 10 and 20 ft-lb transitions at temperatures considerably below those of the semikilled and rimmed ABS-A type of the fractured ships would be superior by an amount equal to the differences in the respective critical temperatures.

Naval Research Laboratory crack-starter tests entailing explosion and drop weight loading of ABS-A steel plates containing a sharp-crack defect[2, 3] corroborated the NBS findings. Fracture initiation in the absence of appreciable deformation could be obtained only at temperatures below the Charpy V 10 ft-lb transition and similarly that fracture propagation through elastic load regions could be obtained only at temperatures below the 20 to 30 ft-lb range. However, for fully killed steels the initiation and propagation of fractures was observed to be possible at temperatures of higher Charpy V energy values. Other studies[2] of quenched and tempered alloy steels showed still greater deviations. Accordingly, it was concluded that the concept of critical temperatures based on Charpy V 10 and 20 ft-lb transitions was not necessarily applicable to steels other than the semikilled and rimmed type investigated by the National Bureau of Standards.

Following these initial findings a critical analysis was made of the fracture characteristics of Charpy V specimens of semikilled and rimmed steels as compared to those of fully killed steels.[4] It was shown that the two types differed in the relation of the fracture

P. P. Puzak, M. E. Schuster, and **W. S. Pellini** are with the Metallurgy Division, Naval Research Laboratory, Washington, D. C.

Scheduled for presentation at the AWS 35th. National Fall Meeting to be held in Chicago, Ill., Nov. 1-5, 1954.

appearance transition to the energy transition. For example, the shear lip developed on the sides of Charpy V specimens of the semikilled and rimmed steels is retained to low energy values of 4–7 ft-lb while for the fully killed steels the shear lip is lost at energy values of 9–23 ft-lb. This was considered to be another indication of basic differences in the fracture characteristics of the two steels which precluded the use of invariant energy levels to define critical temperatures. Because of the limited number of fully killed steels available for the initial investigation[3] and the practical importance of the findings, additional steels have been tested to provide further data for evaluation of the described differences. In addition, the relationship of performance in crack-starter tests to Charpy V test data has been extended to include the fracture and lateral contraction (ductility) transitions of the Charpy test. It was considered that a relationship based on the fracture and ductility transitions of the Charpy V tests would possibly eliminate the differences due to steel type which was indicated by the Charpy V energy transitions.

The procedures for conducting crack-starter explosion and drop weight tests have been described in detail in previous reports.[2, 3] A brief summary is presented in the Appendix for review by readers not familiar with these details or with the improvements in methods developed since the issue of the initial report.

MATERIALS AND METHODS

The chemical analyses, heat treatment, thickness and other details of the steels are presented in Table 1. The ABS-A steels are separated into subgroups of rimmed and semikilled; both types represent as-rolled material (one exception). The ABS-C type is repre-

Table 1

Code*	Thickness, in.	% C	Mn	Si	Al	P	S	Ni	Cr	Mo	Cu	Ti	V
Rimmed (ABS-A)													
31	3/4	0.24	0.45	0.02	—	0.013	0.043	0.12	0.08	—	0.21	..	..
32	1	0.23	0.40	0.01	—	0.010	0.040	0.11	0.06	—	0.33	..	..
33	3/4	0.27	0.41	0.01	0.009	0.037	0.045	0.15	0.14	—	0.30	..	..
34	3/4	0.25	0.35	0.02	—	0.008	0.040	0.18	0.11	0.030	0.19	..	..
35	1	0.24	0.35	0.03	—	0.008	0.039	0.16	0.14	—	0.29	..	..
57	3/4	0.12	0.36	0.01	—	0.006	0.030	0.05	0.07	0.020	0.20	..	..
58	3/4	0.11	0.33	0.01	—	0.019	0.035	0.05	0.13	0.010	0.10	..	..
59	1 1/8	0.19	0.31	0.01	—	0.020	0.028	0.04	0.10	0.020	0.10	..	..
60	5/8	0.21	0.36	0.01	0.010	0.030	0.028	0.05	0.13	0.010	0.10	..	..
61	5/8	0.20	0.37	0.01	0.010	0.020	0.025	0.04	0.10	0.020	0.01	..	..
63	5/8	0.22	0.37	0.01	—	0.008	0.030	0.10	0.10	0.040	0.01	..	..
Semikilled (ABS-A)													
20	1	0.17	0.49	0.10	—	0.007	0.030	0.05	0.11	—	0.11	..	..
22 (A)	3/4	0.25	0.50	0.05	—	0.012	0.036	0.04	0.08	—	0.03	..	..
23	1	0.19	0.49	0.05	—	0.010	0.017	0.05	0.13	—	0.02	..	..
24	1	0.23	0.45	0.05	—	0.009	0.034	0.04	0.08	—	0.01	..	..
25	1	0.24	0.46	0.05	—	0.004	0.024	0.04	0.08	—	0.01	..	..
26	1	0.22	0.45	0.08	—	0.010	0.030	0.04	0.08	—	0.01	..	..
28	1	0.08	0.32	0.02	—	0.011	0.037	0.04	0.03	—	0.03	..	..
47	1	0.25	0.45	0.04	—	0.010	0.028	0.05	0.07	0.020	0.02	..	..
48	1	0.23	0.41	0.04	—	0.006	0.028	0.05	0.07	0.020	0.02	..	..
49	3/4	0.26	0.39	0.10	0.010	0.020	0.028	0.04	0.10	0.020	0.10	..	..
50	3/4	0.24	0.39	0.03	0.010	0.030	0.028	0.05	0.13	0.010	0.10	..	..
51	5/8	0.25	0.36	0.04	0.010	0.020	0.028	0.04	0.10	0.020	0.01	..	..
52	3/4	0.21	0.42	0.02	0.010	0.020	0.025	0.05	0.16	0.020	0.01	..	..
54	3/4	0.19	0.44	0.03	—	0.010	0.037	0.05	0.07	0.020	0.01	..	..
55	3/4	0.21	0.44	0.05	—	0.010	0.037	0.03	0.07	0.020	0.01	..	..
56	3/4	0.29	0.42	0.07	—	0.010	0.039	0.03	0.07	0.020	0.01	..	..
Fully killed (ABS-C)													
40 (N)	1	0.19	0.78	0.24	0.020	0.016	0.045	0.04	0.14	0.030	0.08	..	..
41 (N)	1	0.17	0.70	0.23	0.020	0.015	0.043	0.06	0.17	0.030	0.08	..	..
42 (N)	1	0.19	0.74	0.25	0.020	0.021	0.039	0.10	0.26	0.030	0.08	..	..
43 (N)	1	0.19	0.67	0.21	0.020	0.028	0.039	0.13	0.14	0.030	0.08	..	..
44 (n)	1	0.22	0.77	0.24	0.020	0.010	0.030	0.05	0.11	0.060	0.08	..	..
45 (n)	1	0.17	0.77	0.23	0.020	0.017	0.030	0.05	0.11	0.060	0.08	..	..
46 (n)	1	0.24	0.65	0.24	0.020	0.013	0.043	0.11	0.11	0.030	0.08	..	..
Fully killed (normalized HTS)													
3 (N)	1	0.15	0.95	0.22	—	0.017	0.023	0.11	0.15	0.013	0.19	0.01	0.02
4 (N)	1	0.16	1.33	0.26	0.014	0.021	0.028	0.05	0.26	—	0.01	0.05	0.01
36 (n)	1	0.15	1.02	0.30	0.005	0.024	0.027	0.07	0.20	0.030	0.10	0.05	0.12
37 (n)	1	0.14	1.10	0.28	0.005	0.011	0.038	0.05	0.06	0.030	0.10	0.05	0.10
38 (n)	1	0.13	1.23	0.31	0.005	0.021	0.031	0.05	0.14	0.030	0.10	0.02	0.13
39 (n)	1	0.13	1.05	0.23	0.005	0.017	0.037	0.03	0.06	0.030	0.10	0.00	0.10
64 (n)	3/4	0.17	1.21	0.26	...	0.029	0.039	0.12	0.12	...	0.23	..	0.12
65 (N)	1	0.11	1.17	0.30	0.010	0.027	0.031	0.13	0.13	0.040	0.08	0.02	0.06
66 (N)	1	0.13	0.94	0.27	0.010	0.023	0.021	0.13	0.03	0.030	0.11	0.03	0.06
67 (N)	1	0.16	0.97	0.26	0.010	0.027	0.037	0.20	0.10	0.040	0.10	0.03	0.08
68 (N)	1 3/16	0.16	0.98	0.24	0.010	0.027	0.037	0.20	0.10	0.040	0.10	0.04	0.06
69 (N)	1	0.14	1.06	0.21	0.010	0.027	0.037	0.13	0.10	0.040	0.10	0.05	0.08

* Code numbers 1 to 63 refer to steels reported in previous investigations;[3, 4] additional steels have been numbered consecutively 64 to 69. Percent Al and Mo (—) <0.005. (N) Laboratory normalized. (n) Mill normalized. (A) Laboratory annealed.

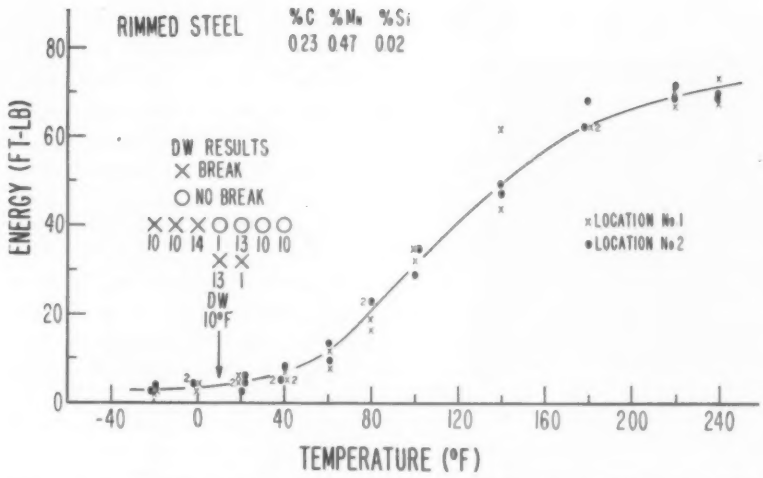

Fig. 1 Illustration of the reproducibility of the drop weight test and relationship to Charpy V transition curve for ABS-A type steels

The drop weight test is used to establish the highest temperature at which a minute amount of deformation is not permissible in the presence of a sharp, crack-like defect. This temperature is termed the "nil-ductility transition." Normally six to eight specimens are required to establish this temperature to the nearest 10° F. Figure 1 illustrates the results of tests entailing a large number of specimens cut randomly from a $^3/_4$ in. thick, 60- x 120-in. plate of rimmed steel. The Charpy V transition curves for diagonal corners of this plate are superimposed as indicated by the points relating to the two positions. The drop weight transition of this steel was established initially as 10° F by the use of the conventional six specimens and the relationship to Charpy V energy was noted to be in the usual range of 5–7 ft-lb. The additional tests serve to illustrate the reproducibility of the drop weight test. As may be observed from Figs. 1 and 2 all specimens except one fractured at 10° F and lower temperatures and all specimens except one resisted fracture at 20° F and higher temperatures.

The presence of the hard-surfacing weld bead which

sented by as-rolled and also by normalized material. The HTS type is represented only by normalized material. The amount of material available permitted conducting both drop weight and explosion crack-starter tests for the majority of the steels.

All Charpy specimens were oriented in the direction of rolling with the notch perpendicular to the plate surface. The crack-starter tests have been demonstrated to be unaffected by orientation; however, for the purposes of record, it should be stated that the hard-surfacing weld was deposited perpendicularly to the direction of rolling for all cases.

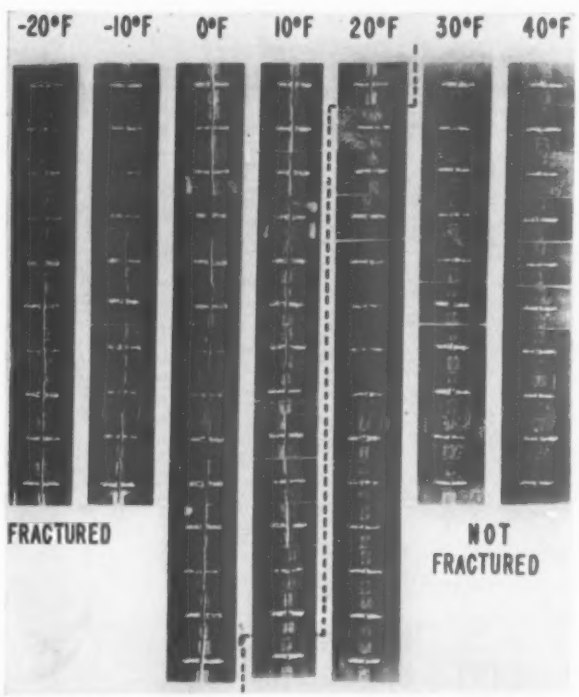

Fig. 2 Specimens used to establish data presented in Fig. 1

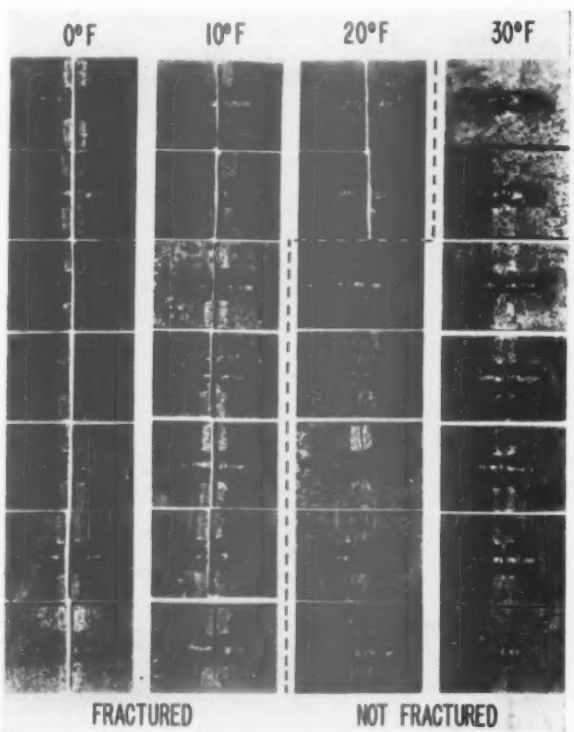

Fig. 3 Results of drop weight tests of specimens heat treated (1100° F) to eliminate the effect of the heat-affected zone. The transition temperature remains unchanged; compare with Fig. 2

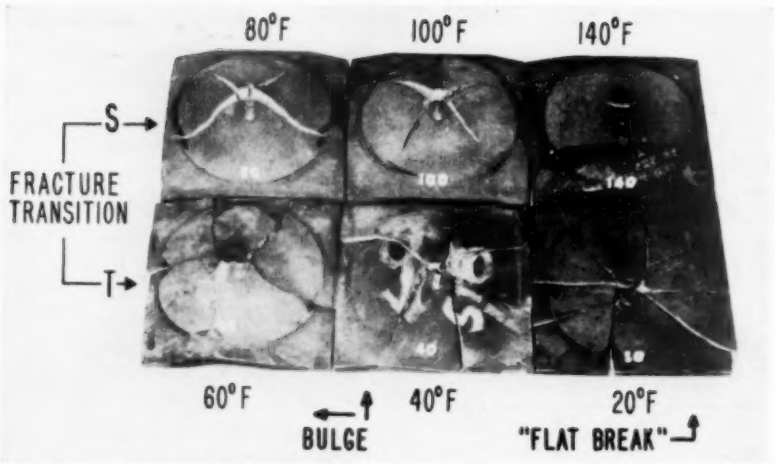

Fig. 4 Crack-starter, explosion test series of a typical ship plate steel (No. 23) depicting T-S fracture transition and ductility transition ("flat break")

serves to develop the sharp crack-like flaw has been interpreted by some to indicate that the test involves weldability aspects. That is, the heat-affected zone influences the test results. To illustrate that this is not so and that the test simply relates to the fracture initiation characteristics of the prime plate material, 28 specimens were taken randomly from the previously mentioned plate and heat treated at 1100° F for 1 hr followed by air cooling. While this heat treatment should not affect the properties of the base plate, the effects of the heat-affected zone should be eliminated. The results of tests of the heat-treated specimens are illustrated in Fig. 3. It is apparent that the transition temperature was not changed by the elimination of the heat-affected zone. Other evidence that the test does not involve weldability may be found in the fact that changes in the shape and size of the weld bead by varying the welding conditions have no affect on the transition temperature. In fact, small arc strikes with associated sharp cracks produce the same effect as the crack-starter weld.[2, 3] The explosion loaded crack-starter tests are conducted in 20° F steps as illustrated in Fig. 4. At the temperature of (or below) the drop weight nil-ductility transition the test plates fracture "flat," i.e., without bulging. At higher temperatures bulge deformation develops indicating a forced initiation of fracture. Because of the ease of determining the nil-ductility temperature by means of the drop weight test no particular note was taken of the "flat break" temperature in the explosion test. The significant features of the explosion test relates to the high-

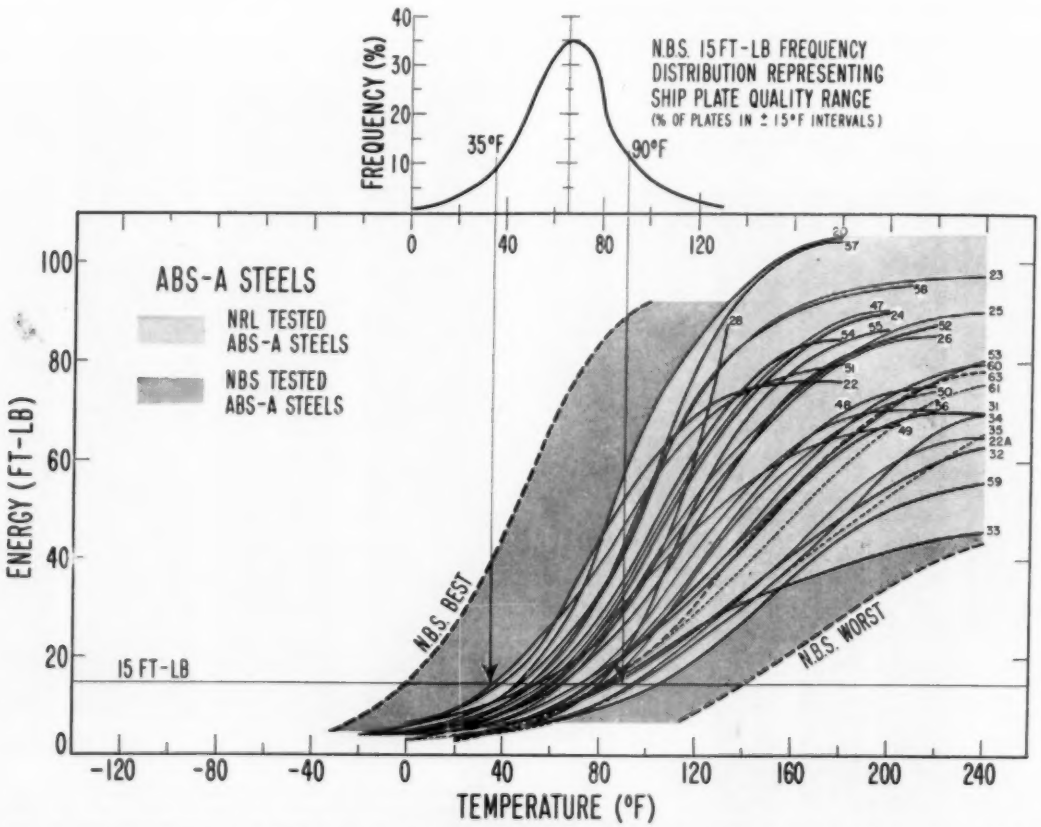

Fig. 5 Charpy V curves of ABS-A steels of this investigation compared to NBS data for ship fracture steels

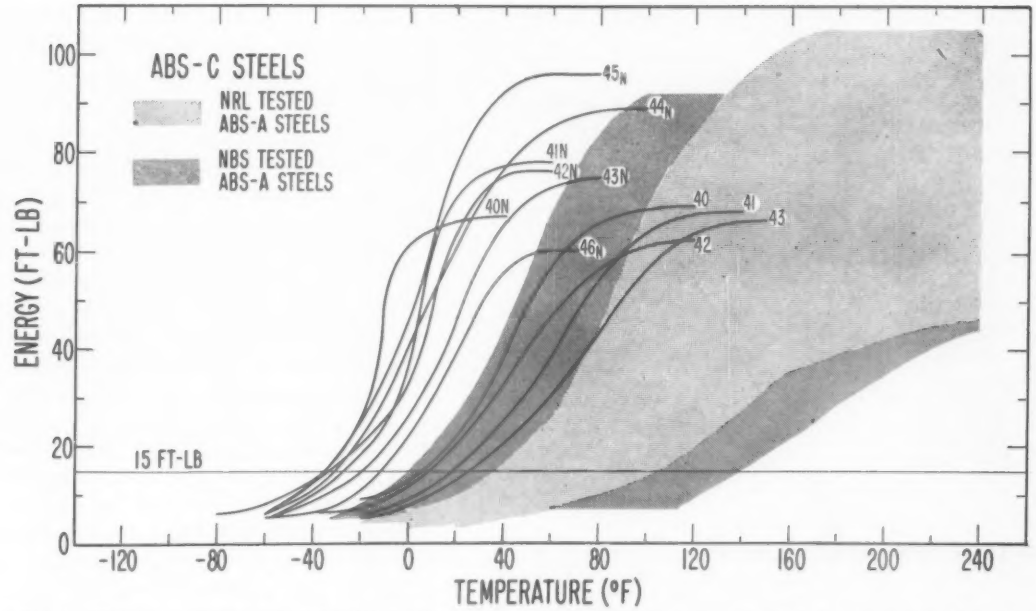

Fig. 6 Charpy V curves of ABS-C (fully killed) steels compared to range of ABS-A (rimmed and semi-killed) steels

est temperature of complete fracture "*T*" (through) which indicates the limit of easy fracture propagation and the next highest (20° F in all cases) temperature which shows propagation of the fracture only in the plastic loaded center regions "*S*" (stop). The *T*–*S* transition thus is taken as the range over which fracture propagation changes from easy to difficult.

CHARPY V TRANSITION DATA

The Charpy V energy transition curves of the various steels subjected to crack-starter tests are presented in Figs. 5, 6 and 7. In Fig. 5 the range of the ABS-A type steels is compared to the range and 15 ft-lb transition temperature distribution obtained by NBS for the

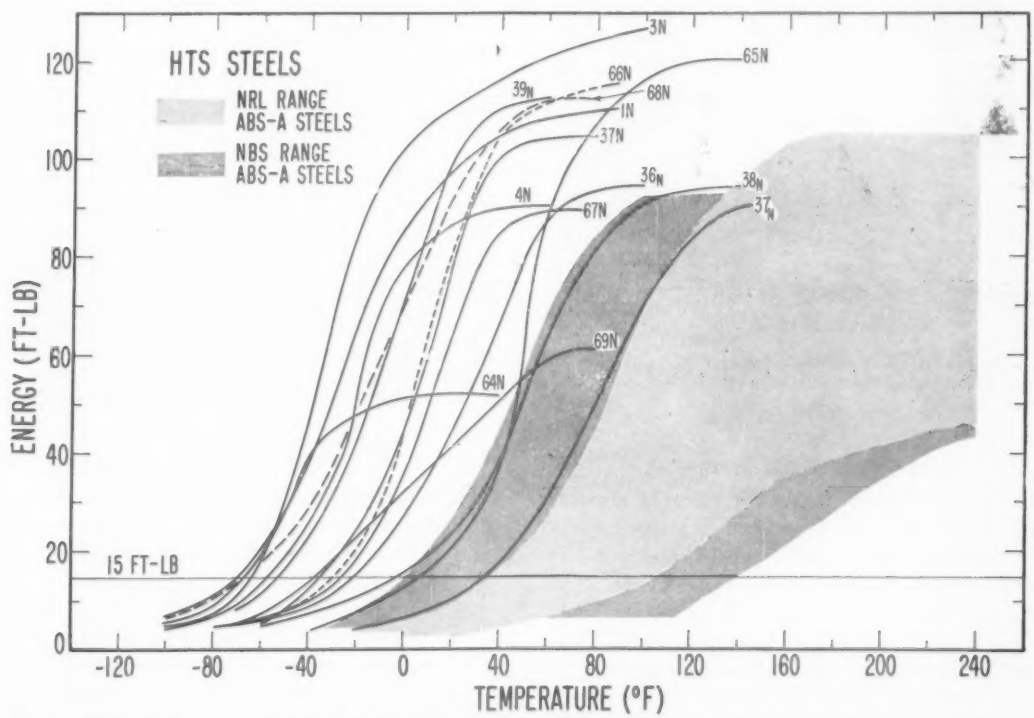

Fig. 7 Charpy V curves of HTS (fully killed) steels compared to range of ABS-A (rimmed and semi-killed) steels

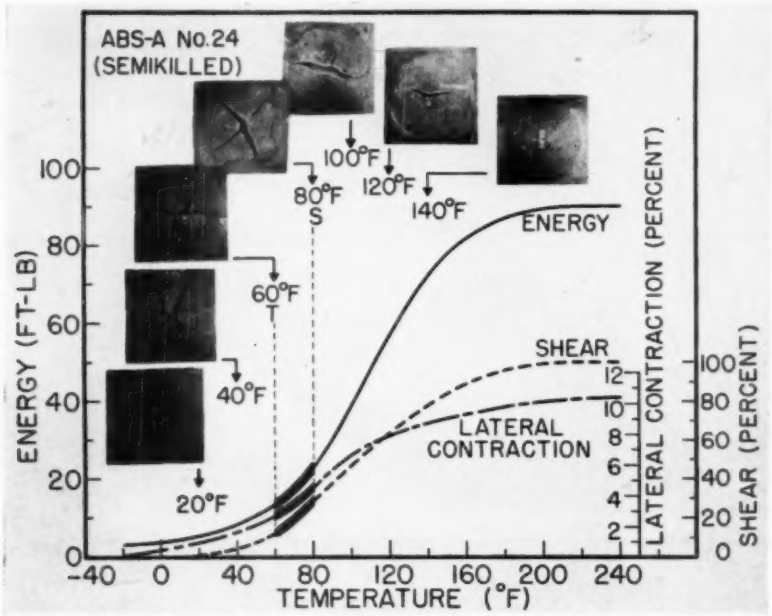

Fig. 8 Typical relation of explosion test T–S transition to Charpy V transitions for ABS-A semikilled and rimmed steels

RELATION TO CRACK-STARTER TESTS

The procedure used to relate the *T–S* fracture transition to the energy, fracture appearance (% shear) and ductility (% lateral contraction) transition curves of the Charpy V test are illustrated in Figs. 8, 9 and 10. The figures also serve to illustrate the typical relationships for the ABS-A, ABS-C and HTS steel types. It should be noted that the *T–S* transition of easy-to-difficult fracture propagation for the ABS-A steel is related to the Charpy V 13–23 ft-lb range, that of the ABS-C steel to the Charpy V 46–78 ft-lb range and that of the HTS steel to the Charpy V 85–102 ft-lb range. It is noteworthy that the ABS-A steel shows almost complete resistance to fracture at values of 60 to 80 ft-lb as may be observed from the 120 and 140° F test pieces of Fig. 8.

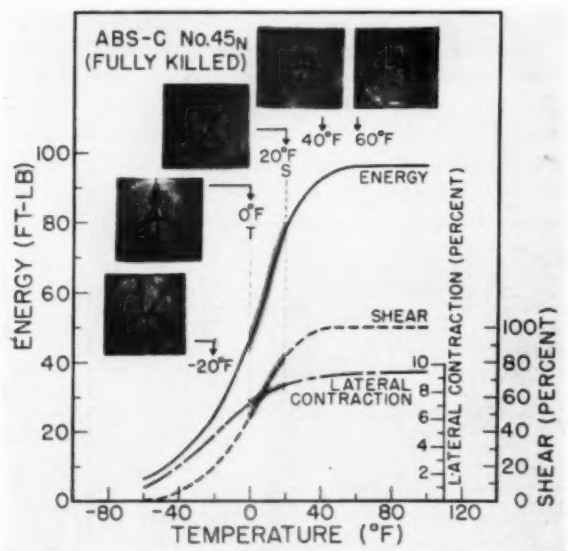

Fig. 9 Typical relation of explosion test T-S transition to Charpy V transitions for ABS-C fully killed steels

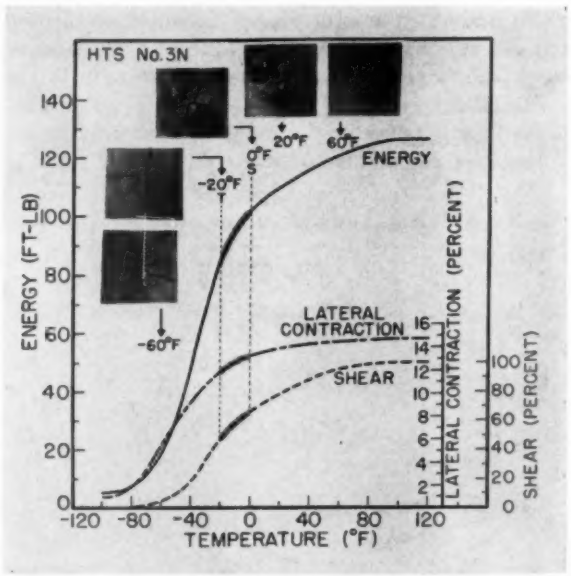

Fig. 10 Typical relation of explosion test T-S transition to Charpy V transitions for HTS fully killed steels

ship fracture steels. It is apparent that the ABS-A steels of this investigation fall in the range of greatest frequency established for the ship fracture steels. Figure 6 illustrates the as-rolled ABS-C steels fall in the lower portion of the ship fracture steel range, while the normalized group falls 20 to 40° F below the lower limit of this range (based on 15 ft-lb transition). The normalized HTS steels cover a very wide range (Fig. 7) —the upper portion of the range overlaps the lower portion of the ABS-A range while the lower portion falls approximately 70° F below the ABS-A range.

Similar comparisons may be made on the basis of the shear and lateral contraction curves. For the ABS-A type steel the *T–S* transition relates to low positions of the respective curves while for the ABS-C and HTS steels the relationships are to higher positions as in the case of the energy curves.

The drop weight test transition was related to the three Charpy V transition curves in the same manner, i.e., the values of energy, % shear and % lateral contraction were determined for the corresponding drop weight transition temperature. Figures 11, 12, 13 and 14 summarize the relationships for each of the steels

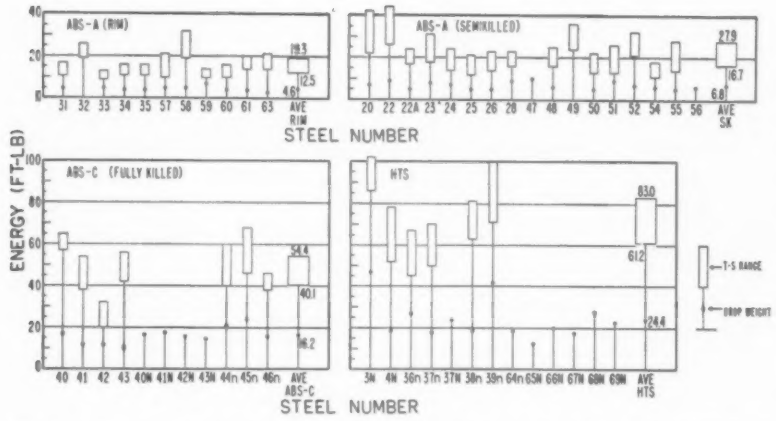

Fig. 11 Charpy V energy values at the fracture transition (T-S) and ductility transition (drop weight test)

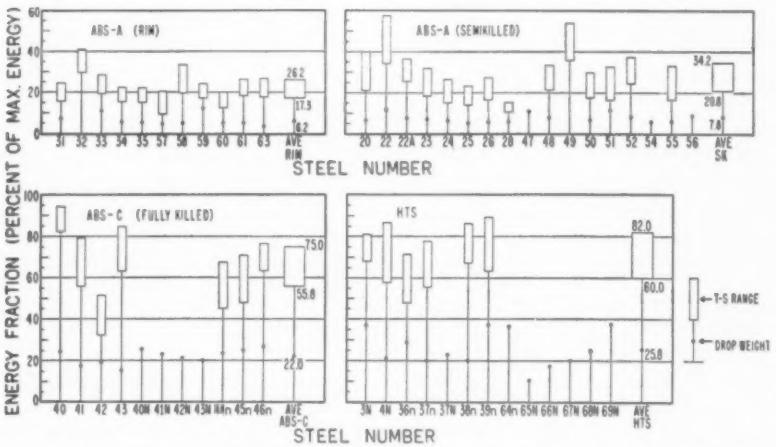

Fig. 12 Charpy V energy fraction values (percent of maximum energy) at the fracture transition (T–S) and ductility transition (drop weight test)

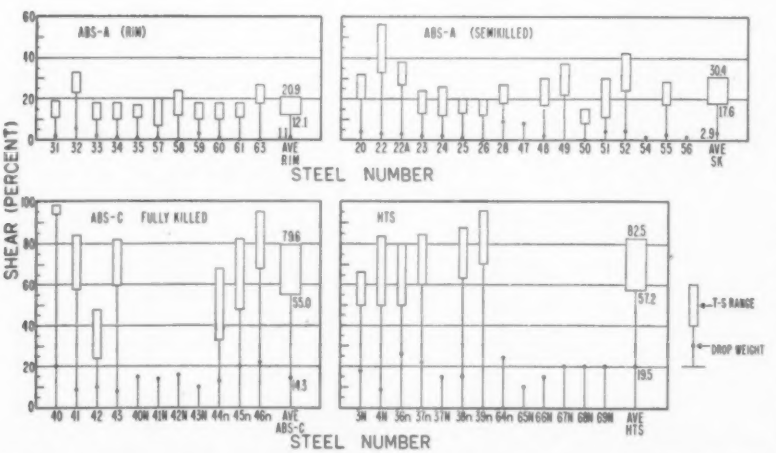

Fig. 13 Charpy V percent shear values at the fracture transition (T–S) and ductility transition (drop weight test)

grouped as to type. Figure 12 presents the energy curve relationships in terms of energy fraction, i.e., the percentage of maximum energy rather than actual energy values. This approach was taken to eliminate possible effects due to variable maximum energy levels of the various steels. The following observations may be made from the various summary graphs:

1. At the highest temperature of easy fracture initiation, as denoted by the drop weight test, the Charpy V energy of the ABS-A steels does not *exceed* 7 ft-lb for rimmed and 10 ft-lb for semikilled steels in any case; the average is 4.6 ft-lb for the rimmed and 6.8 ft-lb for the semikilled steels. For the ABS-C steels the *lowest* energy is 10 ft-lb and the average 16.2 ft-lb. For the HTS steels the *lowest* value is 13 ft-lb and the average 24.4 ft-lb. From these data it may be concluded that the NBS critical energy value of 10 ft-lb max for fracture initiation is confirmed for the ABS-A steels and that the fully killed steels do not follow the same rule.

2. If the highest temperature of easy fracture propagation is taken as the midpoint of the *T–S* range (the top of the band is equivalent to the *S* or stop point and therefore represents difficult propagation) it is observed that for the ABS-A steels the maximum Charpy V energy is 25 ft-lb for the rimmed and 35 ft-lb for the semikilled and that the averages are 16 ft-lb and 22 ft-lb, respectively. For the ABS-C steels the *lowest* value is 26 ft-lb and the average 47 ft-lb. For the HTS steels the lowest value is 56 ft-lb and the average 72 ft-lb. From these data it may be concluded that good agreement is obtained with the NBS critical energy of 19 ft-lb as the limit of easy crack propagation for the ABS-A steels. The fully killed steels do not follow this rule.

3. Comparisons of the ABS-A steels with the fully killed steels based on relationships to energy fraction, % shear and % lateral contraction transitions of the Charpy V test do not eliminate the differences described for the energy curve relationships. The summary data support the observations made from the typical relationships of Figs. 8, 9 and 10. That is to say, there is no advantage to using

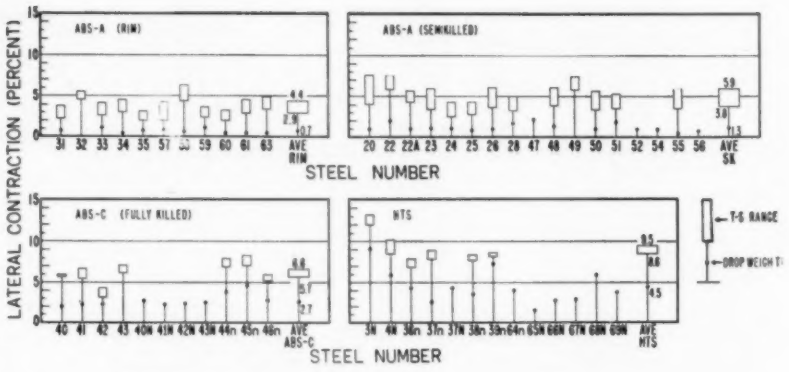

Fig. 14 Charpy V lateral contraction values at the fracture transition (T-S) and ductility transition (drop weight test)

Charpy V transition curves other than that of energy.

COMPARISON CHARPY V AND KEYHOLE

While the Charpy V test is favored by most research investigators the keyhole test is widely used in industry. It has been shown[3, 5] that for ABS-A type steels a correlation exists between Charpy V 10 ft-lb and the midspan of the Charpy keyhole energy transition curve —in most cases the subject Keyhole transition occurs at approximately 20° F below the Charpy V 10 ft-lb temperature. Figure 15 (top) illustrates a typical relationship for ABS-A type steels. Correlation with higher values of the Charpy energy curve is not feasible because of the nearly flat shelf of the keyhole curve as may be observed from the figure cited.

The 20° F differential has been used in the case of fully killed steels to establish the approximate value of the Charpy V 10 ft-lb transition for cases in which only keyhole data were available. The differences in the fracture characteristics of Charpy V specimens of the various steels suggested a critical appraisal of the generality of the subject 20° F differential. Accordingly, Charpy keyhole transition curves were established for the various steels used in this investigation. In many cases the fully killed steels did not correspond to a 20° F differential but rather to a 50° F differential as illustrated in Fig. 15 (bottom). A summary of the relationships between Charpy keyhole midspan and Charpy V 10 ft-lb transitions is presented in Fig. 16.

These and previously discussed data indicate that the practice of adopting the NBS Charpy V 10 ft-lb criterion as the upper temperature of easy fracture initiation and establishing this critical temperature as being 20° F above the keyhole transition temperature may result in considerable error. Consider the case of ABS-C steel 44 (n)* which has a 50° F differential between the keyhole and Charpy V transition temperatures, Fig. 15. A + 20° F correlation would place the assumed Charpy V 10 ft-lb transition at −75° F while actually the Charpy V 10 ft-lb transition is at −40° F. Moreover, the drop weight test indicates easy crack initiation at 21 ft-lb (Fig. 11) which corresponds to −20° F. Thus, the critical temperature for crack initiation is placed 55° F below its actual value (−75° F as compared to −20° F).

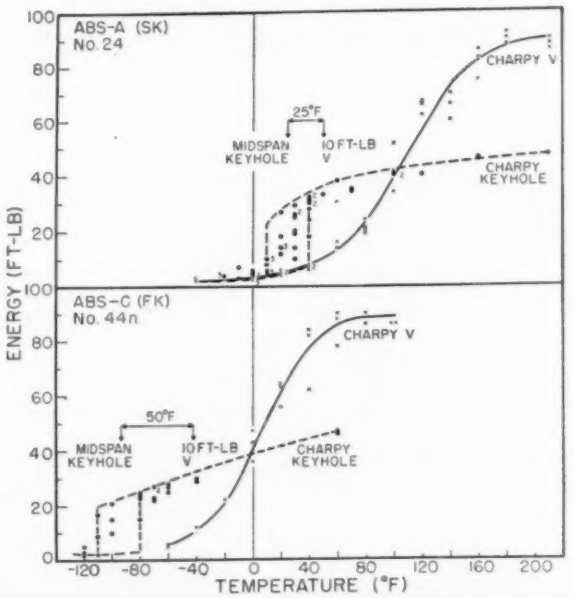

Fig. 15 Relationships of Charpy V and Keyhole energy transition curves for typical ABS-A (semikilled) and ABS-C (fully killed) steels

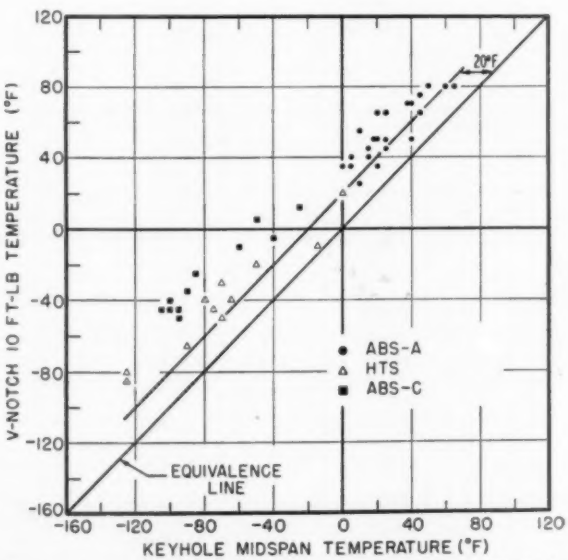

Fig. 16 Correlation of Charpy V 10 ft-lb and Keyhole midspan transitions

APPENDIX

The crack-starter tests are based on the concept that sharp crack-like flaws limit the temperature of safe per-

*(n) = Mill normalized.

formance of welded structures. That is to say, the most damaging defect which may result from fabrication or service is the development of a cleavage crack fault (notch) in or near the weld region. In order to evaluate the performance of steels in the presence of such "ultimate" type flaws a bead of a brittle hard-surfacing type weld is deposited on the test plate. The brittle weld cracks on loading and thus develops a cleavage crack notch in the test material.

The drop weight test involves determining the highest temperature that minute bending (by drop weight loading) is not possible and results in brittle fracture of the steel. The test may be described as a sharp notch ductility transition test based on essentially nil deformation levels. Originally[3] the test was conducted by determining the temperature at which deformation in the order of $^1/_8$% lateral contraction (least value permitting accurate measurement) resulted in fracture. The test procedure was then simplified by the use of a stop which limited bending to 2 deg following the development of the crack in the brittle weld.[2] The same transition temperature is established by either procedure.

The explosion loaded crack-starter test utilizes the same brittle weld used for the drop weight test. The test plate is positioned over a circular die and the plate is loaded by the detonation of an explosive charge in air (18 to 24 in. above the plate surface). The ringlike marks evident on the specimens of Fig. 4 denote the limits of the plate surface which is supported by the die.

The significant feature of this test is the "forcing" of fracture initiation at temperatures above the ductility transition by plastic deformation of the center regions. The fracture propagates for a distance which is related to the fracture resistance at the specific temperature of test. Fractures which propagate through the lightly loaded (die-supported) regions are considered to represent easy fracture propagation and fractures which are contained to the plastic loaded center regions are considered to represent difficult propagation.

Initially[3] the fracture transition (easy to difficult) was taken as the temperature range at which lips of 0.010–0.020 in. developed. This was suggested by the fact that ship fractures never showed shear lips of greater thickness than approximately 0.020 in. It was noted that when the shear lip thickness exceeded 0.020 in. the fractures did not propagate through the edge regions and that the *T–S* concept could be substituted for the shear lip concept to define the critical fracture transition. Actually, this is an excellent confirmation of the initial premise based on the relation to the shear lips of ship fracture surfaces. Because of the ease of observing *T–S* as compared to measuring shear lip thickness all data in this report are related to the *T–S* criterion.

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Committee on Interpretive Reports

The Welding Research Council, impressed by the excellent success of the Materials Division of the Pressure Vessel Research Committee in preparing interpretive reports dealing largely with controversial subjects having to do with pressure vessel steels, their fabrication and use in pressure vessels, has persuaded T. N. Armstrong, Chairman of that Division, to undertake a much broader assignment and cover the entire field of welding research and closely related subjects.

The Committee seeks subjects on which industry would like to have interpretive reports. These subjects must necessarily be of considerable importance to the welding industry and concerning which there is a difference of opinion. Each of these interpretive reports will be prepared by an outstanding expert in the specific field. The reports are not intended to be literature reviews although, of course, selected literature in the field will be carefully screened and will be supplemented by knowledge that may exist but which may never have reached the publication stage. After the first draft of each report, a small committee will prepare a careful summary, giving in concise language and in useful form the substance of the report. Each report is intended to be a summary of the present knowledge of the subject.

T. N. Armstrong, Metallurgist of the International Nickel Co., who is Chairman of the Committee, will undertake to make assignments for the preparation of these reviews as rapidly as possible.

The limited resources of time and money will make it possible to prepare only three or four such reports in any one year. High priority will be given to the most important and urgent fields. At this time industry is being requested to offer suggestions for subjects. In addition to indicating the subject, it would be helpful to the new Committee if the individual making the suggestion would prepare a paragraph indicating the importance of the subject and the need for this information. Communications should be addressed to W. Spraragen, Director, Welding Research Council, 29 W. 39th St., New York 18, N. Y.

Effect of Oxygen on Welding and Brazing Molybdenum

The influence of oxygen on the mechanical properties of heat-treated molybdenum related to welding and brazing

by Timothy Perry, H. S. Spacil and John Wulff

INTRODUCTION

MOLYBDENUM can be joined by a number of different processes including fusion welding, electrical resistance welding (spot and butt welding), percussion welding and brazing. In brazing, the molybdenum seldom exceeds the temperature of 1500° C, whereas in the other processes mentioned, it reaches the fusion point. However, joints made by all of these processes rarely exhibit appreciable room temperature tensile ductility. The present paper presents new data which clarify the effect of oxygen upon these joining processes and discusses the influence of other variables.

As early as 1919, Sykes[1] showed that the microstructure of molybdenum influenced the temperature of the transition range between brittle and ductile failure. Our own work, and the work of others,[2, 3] as presented in this paper, emphasizes Sykes' findings in greater detail.

MATERIALS STUDIED

Three types of molybdenum prepared by different methods were studied. They were:

1. Wrought commercial arc-cast molybdenum.
2. Wrought commercial powder-metallurgy molybdenum.
3. Wrought molybdenum made by rolling metal obtained through reduction of molybdenum pentachloride vapor.[4, 5]

The arc-cast molybdenum had a higher carbon content (0.02–0.04%) than the powder-metallurgy molybdenum (0.01%) and the pentachloride molybdenum (0.01%). The powder-metallurgy molybdenum had a higher oxygen content (0.003%) than the arc-cast molybdenum (0.001%), and the pentachloride molybdenum had the lowest oxygen content of all three materials (<0.001%). The total impurity content of the arc-cast and the powder-metallurgy molybdenum was about the same and was greater than that of the pentachloride molybdenum.

RECRYSTALLIZATION AND GRAIN GROWTH

Pentachloride molybdenum was cold-rolled between stainless steel sheets to a total reduction in area of 87.5%, and in this condition its recrystallization temperature was found to be 870° C.[5] The recrystallization temperatures of arc-cast and powder-metallurgy molybdenum, however, when subjected to similar amounts of cold work were above 1000° C. This difference in recrystallization temperatures is a manifestation of the lower impurity content of the pentachloride molybdenum.

Annealing wrought pentachloride molybdenum into the temperature range from 1000 to 2100° C leads to normal grain growth. In addition, abnormally large grains can be grown if strain or thermal gradients are present during annealing. Wrought arc-cast molybdenum shows grain growth on annealing to temperatures from about 1500 to 2100° C. In that temperature range some normal grain growth is evident, but Bechtold[6] has found that abnormal grain growth is more usual. We have found that wrought powder-metallurgy molybdenum exhibits grain growth only upon annealing in the narrow temperature range of from about 1950 ± 50 to 2100° C, and it is in this range that single crystals can be most easily grown.[7] On annealing any type of wrought molybdenum in the temperature range from 2100° C to the melting point, it is nearly impossible to cause normal or abnormal grain growth.

MECHANICAL BEHAVIOR

Sheet specimens of the three types of molybdenum which had all been subjected to approximately the

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same reduction in area (88%) were annealed for 1 hr at 1050° C in dry hydrogen and tested in tension. The results of this testing are given in Table 1.

Table 1—Tensile Properties Parallel to Rolling Direction of Annealed Molybdenum Sheet

Type of Mo	*Lower yield point, psi*	*Upper yield point, psi*	*Ultimate strength psi*	*Elongation in/in., %*
Arc-cast	54,300	57,600	71,600	23.4
Powder-metallurgy	54,900	56,200	71,500	18.0
Pentachloride	(No yield point)		68,400	19.0

A description of the apparatus used for the tests is given elsewhere.[5]

The grain sizes of the arc-cast and powder-metallurgy molybdenum were about the same, and were finer than that of the pentachloride molybdenum.

The tensile properties of wrought molybdenum are extremely sensitive to annealing procedure. Sheet specimens of wrought powder-metallurgy molybdenum were annealed by Kioka[8] at varying times and temperatures in dry hydrogen and tested in tension. Some results of his testing are given in Table 2.

Table 2—Tensile Properties Parallel to Rolling Direction of Annealed Molybdenum Sheet

Annealing temperature, ° C	*Annealing time, min*	*Elongation in/in., %*
As-rolled		3.7
920	15	18.3
1190	15	0.11

Workers at Battelle,[3] using a bend test as a measure of ductility, have found that one type of commercial $^1/_{16}$-in. molybdenum sheet loses half its ductility in 1 min; another loses half its ductility in 2 min; while wrought arc-cast molybdenum loses half its ductility in 30 sec. Altorffer,[9] in our laboratory, found that the ductility of annealed molybdenum wires was dependent on the time of annealing; the ductility increased to a maximum immediately following recrystallization and decreased with annealing time thereafter at temperatures up to about 1950° C. This effect was more pronounced as the testing temperature was decreased below room temperature. Thus, within limits to be specified later, the longer the annealing time or the higher the annealing temperature, the higher is the transition temperature range.

Sykes and Bechtold[2] found that the larger the grain size of annealed molybdenum, the lower were the yield strength and percentage elongation in room temperature tension testing, provided abnormal grain growth did not occur. Custers[10] found that cross-rolled powder-metallurgy molybdenum sheet, when annealed at 1300° C, has a coarse-grained structure and is brittle at room temperature in tension. Again, the decrease in strength and ductility was greater as the temperature of testing was decreased below room temperature. Therefore, the larger the grain size of wrought molybdenum, annealed at temperatures up to about 1950° C, the higher is the transition temperature range.

Annealing of all three types of molybdenum employed in our study into the temperature range from about 1950 to 2100° C in an atmosphere of hydrogen or purified helium leads to normal or abnormal grain growth, a decrease in tensile strength, and a marked increase in percentage elongation. For such annealed material, we have found that if, in the case of abnormal grain growth, a single grain boundary does not extend completely across a tensile specimen, percentage elongations of from 8 to 40% can be obtained. Workers at Battelle[11] report that molybdenum annealed at 2093° C in high vacuum exhibits an elongation of up to 40%. Some specimens of the molybdenum used in our studies were annealed for us under these conditions at Battelle by Harry Goodwin. We then tested these specimens; the results of this testing are given in Table 3.

Table 3—Tensile Properties Parallel to the Rolling Direction of Annealed Molybdenum Sheet

Type of Mo	*Annealing time, min*	*Elongation in/in., %*
Wrought powder-metallurgy	30	14
	120	17
	270	24
Wrought arc-cast	30	4.7
	120	8.4
	270	15.9
Wrought pentachloride	30	13
	120	8
	270	10

It is evident that the elongation of the pentachloride molybdenum did not improve with time at temperature while the other two types did. As we shall explain later, this is possibly related to its lower impurity content.

ANISOTROPY OF MOLYBDENUM

The work of Kioka[8] with cold-rolled powder-metallurgy molybdenum sheet indicates that the properties of sheet material are extremely anisotropic. The X-ray studies of Semchyshen and Timmons[12] and of Custers and Riemersma[13] show that both straight-rolled and cross-rolled molybdenum sheet has a (100) [110] rolling texture.* Semchyshen and Timmons found that the percentage elongation in tension of straight- and cross-rolled sheet is a maximum at 45 deg to the rolling direction, while the percentage elongation tensile strength of straight-rolled sheet is a minimum at 90 deg to the rolling direction. Ransley and Rooksby[14] and Custers[10] observed that excessive cold reduction in rolling would fissure molybdenum at 45 deg to the rolling direction and perpendicular to the plane of the sheet. We have found that any cold-rolled molybdenum sheet exhibits brittle fracture on

* A (100) plane is parallel to the surface of rolled sheet, and the [110] direction is in the rolling direction.

bending at 45 deg to the rolling direction. The two latter effects would seem to be related to the crystallographic anisotropy of molybdenum; Chen and Maddin[15] demonstrated that single crystals of molybdenum which could be pulled to 50% elongation in tension would fracture by cleavage along the (100) plane in bending at room temperature, and in straight- or cross-rolled molybdenum sheet two (100) planes are oriented perpendicular to the sheet at 45 deg to the rolling direction.

Crystallographic anisotropy cannot explain why Kioka[8] and Semchyshen and Timmons[12] found that the percentage elongation and tensile strength of straight-rolled molybdenum sheet both have their minimum value at 90 deg to the rolling direction. We have found that most cold-rolled commercial molybdenum sheet made from powder-metallurgy arc-cast stock will exfoliate parallel to the surface of the sheet when bent either parallel or perpendicular to the rolling direction as shown in Fig. 1. Analogous behavior may be observed in cold-worked wire or rod. This behavior, we believe, is due to a mechanical anisotropy of submicroscopic inclusions or voids, and has been demonstrated by Backofen in this laboratory[16] to be particularly pronounced in commercial molybdenum, although it is present in metals of the highest purity.[17] That this exfoliation cannot be a crystallographic effect is shown by the fact that molybdenum sheet rolled from pentachloride molybdenum with a low impurity content does not exfoliate on bending. Thus the noncrystallographic anisotropy of molybdenum sheet is probably responsible for its poor qualities perpendicular to the rolling direction.

Molybdenum sheet which has just been recrystallized at moderate temperatures retains the preferred crystallographic orientation described by Semchyshen and Timmons,[12] but the mechanical anisotropy leading to exfoliation has disappeared. Further annealing does not usually destroy the rolling texture in material made from powder-metallurgy stock unless a minimum temperature of about 1950° C is reached. The texture is eliminated in sheet made from arc-cast stock at annealing temperatures above about 1500° C, and we have found that sheet made from pentachloride molybdenum loses its rolling texture above about 1200° C. Annealing all three types of molybdenum at 2093° C causes complete disappearance of the rolling texture. To avoid the formation of a rolling texture during the manufacture of molybdenum sheet, Semchyshen and Timmons[12] recommend the practice of compression rolling* whereas Custers[10] suggests cross-rolling accompanied by a not very clearly defined heat treatment between each pass. It also appears that the temperatures at which rolled molybdenum loses its texture are also dependent on the oxygen and carbon contents of the material.

OXIDES IN MOLYBDENUM

Parke and Ham[18] and Woodside[19] have shown that the forgeability of arc-cast molybdenum can be correlated with fractographic observations, and Zappfe and co-workers[20] have published extensive papers on the fractography of cast molybdenum. A fracture facet of molybdenum is examined at high magnification for oxides on the surface of the facet. The addition of carbon to arc-cast molybdenum results in the appearance of carbides on the fracture facets and the disappearance of oxides. In our laboratories, Moffatt[5] used fractographic techniques for investigating the presence of oxides, carbides and nitrides in molybdenum. The oxide present in fractures has been identified by electron diffraction as MoO_2.[21] Our fractographic studies showed that this oxide completely covers the grain boundaries in oxygen-rich arc-cast molybdenum (0.01% oxygen), while in highly purified molybdenum, the oxide is present on grain boundaries in the form of scattered chevrons. It was also found that oxides and carbides could exist simultaneously when the carbon content of the arc-cast molybdenum was below about 0.04%.

Our studies showed that all commercial wrought molybdenum of less than about 0.02% carbon contains oxides at grain boundaries as chevrons or thin films after annealing above about 2100° C. Only rarely were these formations found in commercial wrought molybdenum annealed below about 1950° C; this apparent lack of oxide is in part due to the small grain size of powder-metallurgy molybdenum annealed below that temperature which makes fractographic examination extremely difficult. Also, while large grains can be grown in wrought arc-cast molybdenum upon annealing below 1950° C, fractures in this material are primarily transgranular and can hardly reveal the presence of grain boundary oxides. Normal metallographic sectioning followed by polishing and etching also failed to show the form and location of oxide in molybdenum annealed below 1950° C. Evidently, this oxide is present in wrought molybdenum annealed below 1950° C as inclusions of submicroscopic size.

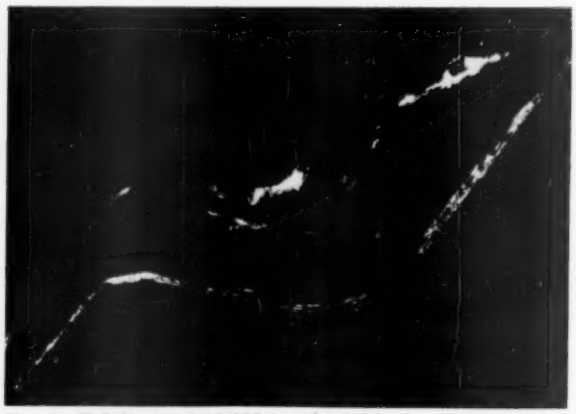

Fig. 1 Exfoliation in 0.008-in. thick Mo sheet subjected to five cycles of reverse bending. ×50. Unetched

* Compression rolling consists of rolling carried out by rotating the work through an angle of a few degrees after each pass through the rolls.

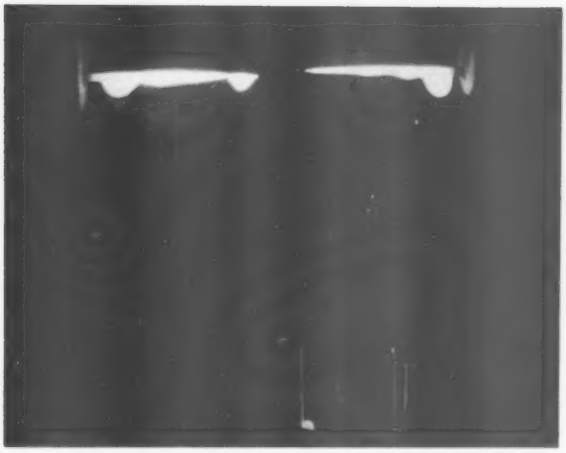

Fig. 2 Photograph of drops of liquid oxide eutectic being formed on heating Mo wire in O_2 containing atmosphere. ×1

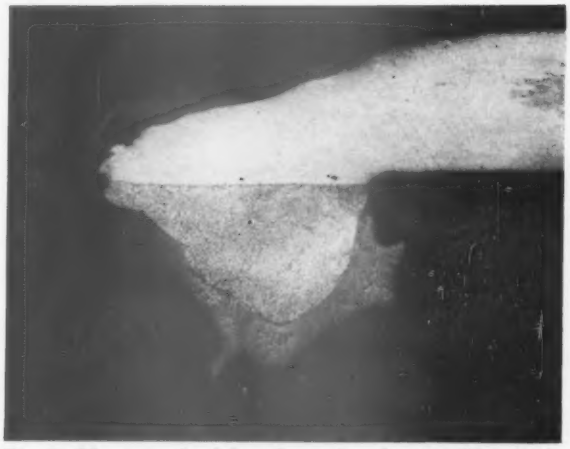

Fig. 3 Macrograph of drop formed on heating Mo wire in an O_2 containing atmosphere. ×25. Etched

In a series of experiments on molybdenum oxides carried out in our laboratories, a molybdenum wire was heated by electrical resistance in a helium atmosphere containing known amounts of oxygen. When the wire was heated to any temperature above about 500° C in the presence of oxygen, molybdenum trioxide vapor was formed, and, just before failure of the wire occurred, drops of liquid were observed clinging to the wire as shown in Fig. 2. Figure 3 shows a cross section of one of these drops in contact with a severely oxidized remnant of the molybdenum wire. Figure 4 is a photomicrograph of the boundary dividing the two sections of the drop shown in Fig. 3. X-ray diffraction studies of a powder sample composed of such drops showed that the only materials present in the solidified drop were molybdenum and MoO_2. This result indicated that the liquid drops were a eutectic mixture of molybdenum and MoO_2; accordingly samples of mixed molybdenum and MoO_2 powders were prepared and heated in argon gas to determine the temperature at which eutectic melting of these two components took place. Our best measurements indicate that this temperature is between 2100 and 2150° C. Figure 5 is a micrograph of the wall of a molybdenum cylinder which has been filled with MoO_2 and then heated to about 2150° C for 5 min; at this temperature eutectic melting has taken place, and the eutectic liquid has wet and penetrated the molybdenum grain boundaries.

When a molybdenum wire was heated rapidly in purified helium to any temperature above 2100° C, it was always more brittle than a similar wire heated slowly in the same atmosphere. And, if a wire was brought as rapidly as possible to a temperature of 2500° C, a puff of white vapor was given off by the wire just before failure. A macrograph of a $^1/_{16}$-in. powder-metallurgy molybdenum wire heated in this manner is shown in Fig. 6. The number and size of the pores evident in this material hardly indicate residual gases such as H_2, CO or N_2 in the molybdenum as their cause. This type of porosity was first observed by Davenport[22] in 1927. He showed that both tungsten and molybdenum exhibited microporosity when heated to high temperatures, but no explanation of this porosity was advanced except for the suggestion

Fig. 4 Micrograph of drop shown in Fig. 3. ×1500. Unetched (reduced one-third in reproduction)

Fig. 5 Micrograph of cross-sectional view of Mo-MoO_2 interface illustrating penetration of Mo grain boundary by eutectic liquid. ×400. (Reduced one-third in reproduction)

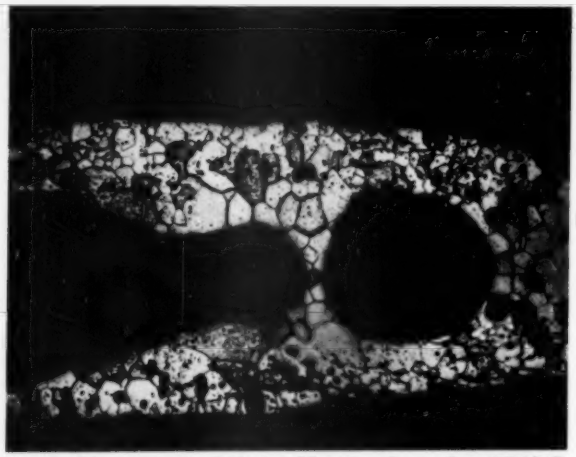

Fig. 6 Macrograph of 1/16-in. Mo wire, heated to 2500° C, showing porosity induced in the wire by heating. ×20. Etched

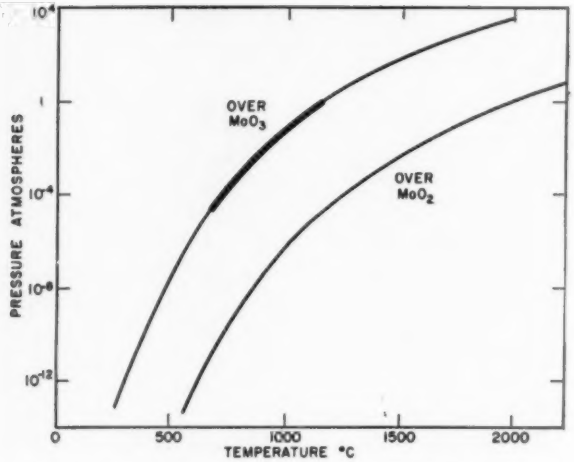

Fig. 7 Vapor pressure of molybdenum trioxide over different oxides

that they were due to occluded gases. In our own work, the white vapor given off by molybdenum wires prior to failure suggested that the gas responsible for the voids might be molybdenum trioxide. Therefore, calculations were made from current thermodynamic data of the vapor pressure of molybdenum trioxide over solid trioxide and over solid dioxide in contact with molybdenum.[23] The results of these calculations are shown in Fig. 7 and they agree well with similar calculations made recently by Brewer.[24] It is evident from Fig. 7 that the vapor pressure of molybdenum trioxide over solid dioxide in contact with molybdenum can reach a value of several atmospheres at temperatures below the melting point of molybdenum. This high trioxide vapor pressure, together with the low yield strength of molybdenum near its melting point, could account for the pores formed at 2500° C in molybdenum metal.

It was also found, when a molybdenum wire was heated into the temperature range from about 1100 to 2100° C in an atmosphere containing oxygen, that the wire was brittle at room temperature. Maddin[25] has found that single crystals of molybdenum treated in the same manner are ductile in tension at room temperature, but that similarly treated specimens consisting of a few large grains will fail by intergranular fracture during testing. Thus diffusion of oxygen along the grain boundaries of molybdenum must be more rapid than volume diffusion through the metal.

When a molybdenum wire was heated in a purified helium atmosphere so that the central portion of the wire reached a temperature between about 1950 and 2150° C, this section of the wire was ductile at room temperature while the remainder of the wire was brittle. After such treatment, the central section of the wire would often consist of a single crystal of molybdenum. With the aid of radiation shields, a section of wire about 2 in. long could be raised to a temperature between 1950 and 2100° C. Tensile specimens made from this wire showed percentage elongations of up to 40%. Efforts to determine the reason for this ductility by metallographic examination were successful only after many trials. Fractures of the ductile molybdenum were always transgranular and contained spheroidal inclusions. By suitable preparation of the fracture surface, it was possible to identify these inclusions as molybdenum dioxide. Figure 8 is a micrograph showing such inclusions delineating a former grain boundary in what has become a single large grain of molybdenum. The conversion of undissolved oxides in molybdenum into such spheroids allows grain growth to take place and reduces the stress-raising effect of the oxide inclusions.

DISCUSSION AND CONCLUSIONS

Disregarding, for the present, the necessity of protecting molybdenum against catastrophic oxidation when it is exposed to oxygen-containing atmospheres at temperatures above 500° C, then the factors which limit the applicability of molybdenum from a fabrication and use standpoint are:

1. Dependence of forgeability on composition.
2. Crystallographic anisotropy resulting from working.
3. Composition-dependent noncrystallographic anisotropy resulting from working.
4. Embrittlement induced by heating below 1950° C (brazing).
5. Embrittlement induced by heating above 2100° C (welding).

From the material presented in previous portions of this paper, it is obvious that oxygen affects each of the factors listed above.

To summarize our findings, each of these points will now be discussed in turn.

1. The necessity for control of the oxygen content of arc-cast molybdenum has been pointed out many times. This is due to the fact that the high as well as the low temperature brittleness of arc-cast molybdenum ingots results from an intergranular layer of

molybdenum dioxide. In addition, the disproportionation of the dioxide to trioxide vapor may cause voids which adversely affect the properties of the material. In molybdenum powder compacts which are sintered at 1700 to 1800° C, there is a possibility of oxygen transport to grain boundaries since, as will be pointed out later, some form of submicroscopic grain boundary precipitate is apparently the stable form of oxygen in molybdenum below about 1950° C. This precipitate, although differing in form from the readily observable sheets of molybdenum dioxide found in oxygen-rich arc-cast molybdenum ingots, can cause the embrittlement of sintered powder-metallurgy molybdenum. In both arc-cast and powder-metallurgy molybdenum, this oxide is broken up and redistributed throughout the metal during forging and other working of the material.

2. The work of Chen and Maddin[15] shows clearly that molybdenum crystals are anisotropic. The anisotropy of single crystals is responsible for the anisotropy of preferentially oriented polycrystalline molybdenum and explains the brittle fracture of molybdenum sheet at 45 deg to the rolling direction as a cleavage fracture along a set of (100) atomic planes. Oxygen itself cannot influence this crystallographic anisotropy, but oxide inclusions are capable of acting as stress raisers which can initiate cleavage.

3. The exfoliation of molybdenum sheet and rod or wire during bending is directly dependent upon undissolved impurities such as oxides and carbides which have been preferentially distributed by hot and cold working.

4. The embrittlement of molybdenum containing less than 0.02% carbon on heating into the temperature range from the recrystallization temperature to about 1950° C has not been satisfactorily explained. In wrought molybdenum, the degree of embrittlement is very dependent upon the annealing practice employed.[8] It should be remembered that crystallographic anisotropy may exist in wrought molybdenum after such treatment since the recrystallization texture is the same as the rolling texture. However, the effects of noncrystallographic anisotropy quickly disappear with time at temperature. As stated before, metallographic examination has revealed no reason for this behavior, but the lack of grain growth in this material below 1950° C suggests that oxide precipitates at this temperature are intergranular and inhibit grain growth. This hypothesis is supported by the following observations: (1) heating molybdenum of low carbon content above 1950° C, so that oxide inclusions become visible as spheres, allows grain growth to occur very rapidly; (2) single crystals of molybdenum remain ductile when heated in oxygen, whereas polycrystalline material rapidly becomes brittle. Thus the stable form of oxygen below 1950° C probably is a submicroscopic, grain boundary oxide precipitate, while above 1950° C, but below the eutectic temperature of 2100° C, the stable form is that of spheroids distributed both in grain boundaries and the interior of grains (Fig. 8). A grain boundary oxide precipitate formed in wrought molybdenum on annealing below 1950° C also explains the loss of noncrystallographic anisotropy during annealing, since the formation of such a precipitate would necessarily involve the destruction of the structure of oxide inclusions formed during cold working. As noted previously, fractures in molybdenum annealed below 1950° C are primarily transgranular rather than intergranular, but this fact does not eliminate the possibility of a grain boundary precipitate in the material since a discontinuous oxide precipitate could be formed which would not lead to intergranular fracture. Of importance is the fact that annealing low-carbon commercial wrought molybdenum in the temperature range from 1950 to 2100° C leads to the formation of spheroidal oxide inclusions which result in a ductile material.

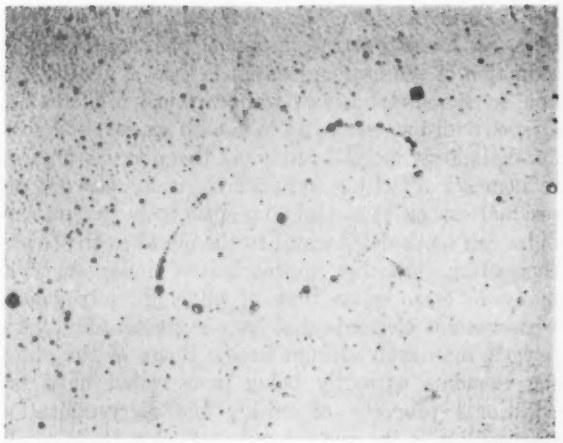

Fig. 8 Inclusions left within a single grain on holding for 1 hr at 2030° C. ×1000. Lightly etched. (Reduced one-third in reproduction)

5. The low ductility of molybdenum that has been heated above 2100° C is due to the low melting point of the molybdenum-molybdenum dioxide eutectic and the ease with which it can wet molybdenum, since the molten eutectic liquid can spread throughout the grain boundaries to form a grain boundary precipitate that leads to intergranular fracture at room temperature. For this reason, most fusion and resistance welds in molybdenum are brittle at room temperature. Ductile welds can be made if the weldment is subjected to sufficient plastic deformation[26] to break up and redistribute the grain boundary oxide formed during welding in the same manner that arc-cast or powder-metallurgy molybdenum stock must be worked before becoming ductile. The high pressure of molybdenum trioxide vapor leads to the porosity often observed in weldments.

Some of the limitations of molybdenum discussed could doubtless be eliminated if the oxygen content of the metal were kept below the solubility limit. This value, however, is both very small and unknown. The preparation of relatively oxygen-free molybdenum by reduction of the pentachloride, by double vacuum melting, or by vacuum annealing in the range from

1950 to 2100° C now appears feasible only in the laboratory. A more practical approach to the problem of reduction of the oxygen content is that of adding carbon to the molybdenum to form carbon monoxide. Carbon additions can be made to both arc-cast and powder-metallurgy molybdenum, and this practice requires refinements in melting and sintering techniques to keep residual carbon at a minimum since molybdenum carbides can be as detrimental to the metal as the oxides themselves. Another approach now under study in many laboratories is that of alloying molybdenum with metallic elements that have a greater affinity for oxygen than molybdenum itself. Some of the alloying elements currently being investigated have the additional property of raising the recrystallization temperature of the molybdenum. Such material could be brazed with suitable filler metals at a temperature below its recrystallization temperature, thus avoiding embrittlement. However, the selection of alloying elements for molybdenum has been governed primarily by their affinity for oxygen, while as a result of our own work we feel that further criteria are required; these criteria should include:

1. High melting point of the oxide formed (or of any eutectic formed).
2. Nonwetting of molybdenum by the molten oxide to prevent spreading of the oxide in grain boundaries.
3. A tendency for the solid oxide to spheroidize and reduce its effect as a stress raiser.
4. A lowering of the pressure of molybdenum trioxide vapor.

On adding a metallic element to oxygen-containing molybdenum, a ternary alloy system of molybdenum-oxygen-alloying element is formed. The oxide present in this alloy may be a complex oxide involving all three components, and the same situation may apply regarding eutectic formation. In general, the eutectic point of a ternary alloy system occurs at a lower temperature than the eutectic formed between any two components so that most metallic elements probably lower the temperature of formation of a liquid oxide or eutectic.

The tendency of a liquid phase to wet grain boundaries and the tendency of a solid phase to spheroidize are both directly dependent on the interfacial energies between the phases involved. It is also a general rule that a solid or liquid complex oxide tends to have a lower interfacial energy than a pure oxide, so that unless the alloying agent has an affinity for oxygen which is extremely great, the formation of a ternary molybdenum-oxygen-alloying element alloy will probably increase the tendency of liquid oxide or eutectic to wet grain boundaries and increase the tendency of solid oxide to spheroidize. On the other hand, the activity of oxygen in such a complex oxide or eutectic would be reduced so that the pressure of molybdenum trioxide vapor is lowered.

Carbon as an addition agent has the shortcoming that it leads to an eutectic between molybdenum and molybdenum carbide at 2200° C which might be expected to behave in a manner analogous to the molybdenum-molybdenum dioxide eutectic. In addition, the solubility of carbon in molybdenum at 2200° C is about 0.1%, so that considerable precipitation of molybdenum carbides will occur on cooling molybdenum from high temperatures. Either eutectic melting or high carbon solubility will impair the ductility of carbon-containing molybdenum which has been welded; as evidence of this behavior, workers at Battelle[11] have found in butt-welded arc-cast molybdenum that all grains in the weld were surrounded by carbides. However, since grain growth can occur in commercial carbon-containing molybdenum at a temperature of 1500° C, but does not start in carbon-free molybdenum until a temperature of 1950° C is reached, carbon acts to reduce the inhibition of grain growth by oxides. This action may be due to either a decrease in the amount of oxide present in the material or to a tendency of the oxide to spheroidize at a lower temperature than normally.

Perhaps the most promising developments in improving the mechanical properties and weldability of molybdenum will be based upon the use of both metallic alloying elements and carbon as addition agents. This practice could result in the formation of very high melting point complex carbides, of molybdenum and the alloying element, which are formed from the residual carbon remaining after deoxidation of the metal. Carbides as a class of materials have higher melting points than oxides, and if conditions of interfacial energy were favorable, these carbides could spheroidize both in the liquid and the solid state to result in a material of good weldability having room temperature ductility.

ACKNOWLEDGMENT

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Joining of Molybdenum

A literature review on joining molybdenum and a metallurgical study of the subject

by James H. Johnston, Harry Udin and John Wulff

INTRODUCTION

THE purpose of this paper is to review the literature on the joining of molybdenum, to discuss experiments carried out at M.I.T. during the past two years, and finally to discuss critically the results obtained in the light of the metallurgical findings presented in a previous paper from this laboratory.[24]

An excellent review of the literature prior to 1941 has been conducted by Spraragen and Claussen.[1]

Arc welding of molybdenum metal has been described by Nichols, Nolan and Young[2] who applied the term "pseudoweld" to the finished weldments because of their extraordinary brittleness. They ascribed the embrittlement to the precipitation of an oxide of molybdenum at grain boundaries. Quantitative effects of oxygen and nitrogen on fusion weldments of molybdenum have been investigated by Johnston.[3] It was found that the amount of oxygen contained in commercial molybdenum alone is sufficient to cause severely embrittled arc weldments in a highly purified inert atmosphere. Heuschkel[4, 5] has also described inert arc welding of molybdenum and observes the brittle nature of the joint produced.

Arc welding of tantalum metal,[6, 7] a metal somewhat similar to molybdenum, is frequently conducted under a pool of carbon tetrachloride or water. Espe and Knoll[8] discuss welding of molybdenum in a pool of CCl_4. None of these writers reports ductility.

An interesting approach to the problem of fusion welding of molybdenum was employed by Goodman,[9] who tried submerged melt welding. However, he did not report physical properties of the joint produced. The fluxes used were standard steel welding fluxes with variations. Two items make this method difficult. The first is that the reaction of metal oxides in the fluxes with molybdenum forms molybdenum oxide, such as would happen to silica or MnO contained in these fluxes, and is sufficiently "to the right" to provide a deleterious amount of oxygen to the molybdenum weldment. The second is that were the fluxing actions of perhaps metal halide fluxes powerful enough to actually dissolve and remove molybdenum oxide from the melt, an embrittled condition at the edge of the fusion zone in the base metal may still be present in today's commercial molybdenum that has been overheated. The identical criticism also applies to the methods of carbon arc welding of molybdenum in a pool of CCl_4. Another obvious criticism of the latter method is the accompanying formation of phosgene gas.

Both the use of submerged melt welding and carbon tetrachloride are of considerable interest, however, because good quality molybdenum capable of being overheated somewhat without severe room temperature embrittlement is beginning to appear on the market in limited but growing quantities.

It is now generally acknowledged among research centers and manufacturers in the molybdenum field, that fusion welding of molybdenum does not offer much promise at the present state of development of arc welding. Satisfactory arc welding can be accomplished with resultant ductility on only the highest quality vacuum arc-cast carbon deoxidized molybdenum and under only the strictest atmospheric control.[3] It cannot be accomplished with ductility at present with molybdenum made by powder metallurgy. Unfortunately, the extent to which helium or argon must be purified in order to avoid excessive contamination of even the best quality molybdenum is commercially prohibitive and can be accomplished with success only in the laboratory. The one hopeful avenue of approach appears to be the development of molybdenum containing a deoxidant (or an addition with a profound influence on the precipitation and surface tension mechanisms of the molybdenum oxide) powerful enough to overcome the effects of air. This approach is being followed at other laboratories, although the characteristics desired are not directly for ease of welding.

Resistance welding methods have been studied most. In brief, all the writers, except two, have reported failure with respect to achieving ductility. Very

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careful work at Battelle Memorial Institute[10] on high-vacuum butt welding has produced several welds with room temperature ductility. Kiefer,[11] in a study of the welding of refractory metals, reported a ductile spot weld done in air on small diameter wire.

It should be noted that in all the preceding and following discussion the term "embrittled" is an expression of the brittle-ductile transition behavior observed in molybdenum and other B.C.C. metals. "Embrittled" molybdenum is molybdenum which undergoes no gross plastic deformation prior to brittle failure. Most work in welding has been reported for tests made at room temperature. Thus embrittled molybdenum may be ductile at slightly elevated temperatures, and the exact temperature for its transition from brittle to ductile behavior is dependent upon specimen geometry and strain rate as well as metallurgical factors such as purity. There is no way of estimating the transition temperature for work on welding done in the past except to note that the transition temperature is either above or below room temperature depending upon whether the metal was brittle or ductile, respectively.

The difficulties encountered in spot welding molybdenum are electrode contamination (sticking to the electrode) and deformation of the electrodes and brittleness of the joint produced. Electrode sticking has been reduced by Espe and Knoll[8] by using thin tantalum foil next to the electrode.

Espe and Knoll have also tried spot welder brazing with a Ag-Ni-Cu powder containing wolfram powder, and extensive use of nickel sheet for spot welding is made industrially.

Molybdenum sheet made by powder-metallurgy methods exfoliates parallel to the sheet. Its strength perpendicular to the sheet is very low. Although Jeffries[12] observed that hammer forging split tungsten at 1800° C, it did not reweld the split; he did observe, however, that welding reoccurred by electrical heating. It should be noted in this respect as in other behavior that molybdenum is similar to wolfram. Johnston[3] states that the fractured split surface of molybdenum sheet is similar in appearance to high-oxygen, cast-molybdenum fractures. This tendency of molybdenum sheet to behave like a pack of playing cards must be considered when designing lapping spot-welded joints in molybdenum sheet.

The electronics industry has for many years used nickel or platinum foil sandwiched between molybdenum sheet or wire for spot welding. Although the use of nickel foil would more properly be termed brazing, use of zirconium,[13] tantalum and platinum might produce a high-temperature-service joint. Whether or not any of these joints have ductility still remains to be determined. Of this group tantalum and zirconium exhibit complete solid solubility with molybdenum,[14] but bulk zirconium or titanium additions should be avoided because of poor oxidation resistance. Most other metals form metal compounds with molybdenum and are not expected to reveal ductile behavior. There is also some doubt as to the use of tantalum as a means of joining molybdenum.[14-15] Although it has high "reactivity" and solubility for oxygen and should absorb surface layers of oxygen and molybdenum oxide, without impairing its own ductile behavior too much, there is evidence that more than 5% molybdenum in tantalum causes the solubility of oxygen in the tantalum to become decreased to a deleterious amount, embrittling the layer of tantalum. At 10% molybdenum and greater, tantalum alloys become unworkable cold. This interpretation of the effects of molybdenum is made by the author on work done by Myers.[15]

A thin layer of a brittle compound or embrittled tantalum between molybdenum weld surfaces will not necessarily cause the weld zone to behave in a brittle fashion as would the brittle material if it were in bulk; however, this is not common experience, and neither a stress analysis nor confirming experiment have been reported.

Myers[15] was, perhaps, not aware of the extent of the critical nature of oxygen content on the ductility of the metals Mo, W and Ta. Although he used the most careful powder metallurgy vacuum techniques, the alloys were nevertheless high in oxygen content. It would appear then that the use of tantalum under more powerful reducing conditions than relatively dry hydrogen or vacuum, as perhaps might be the case with carbon tetrachloride, might be of considerable aid in welding molybdenum. Use might be made of a tantalum-molybdenum interface as a thermocouple to measure temperature.

Percussion welding of molybdenum has been done by Skinner and Chubb[16] and by Heuschkel.[5] It offers promise as is shown in later sections of this report.

Brazing of molybdenum to nearly all common metals and many alloys has been dissussed by Espe and Knoll,[8] and Müller and Clay.[17] None of these writers has reported physical properties of the joint produced. Nickel is by far the most popular medium, yet as with most other brazing materials, it forms a brittle intermetallic compound with molybdenum. The problem is essentially one of:

1. Choosing an alloy whose melting point is raised by loss of one of the constituents by diffusion or evaporation in order to avoid overheating the molybdenum into the embrittling range, but still secure a high temperature joint.
2. Cleaning surface oxides and adsorbed gases.
3. Keeping the time and temperature long and high enough to raise the melting point of the filler alloy.
4. Keeping time and temperature short enough to prevent much diffusion of nickel or other elements and to prevent the extensive formation of metal-molybdenum compounds.
5. Joint design.

Mechanical joints of molybdenum sheet to molybdenum sheet are very attractive in some respects because of the lack of extreme temperatures and subse-

quent embrittlement. The principal difficulty other than joint design is the necessity to "cold" work molybdenum at temperatures in excess of room temperature namely from 300 to 1000° C, in order to avoid brittle failure. Commercial molybdenum metal has pronounced mechanical anisotropy and it is essential that the "fiber" orientation be parallel to the direction of the applied service stresses. In addition to this wrought iron type of behavior, molybdenum sheet exfoliates under very little stress normal to the working directions and this must also be considered in joint design.

Since tantalum metal has considerably better plastic properties at room temperature than molybdenum, has essentially the same elevated temperature properties, and forms complete solid solution with molybdenum, rivets of tantalum for joining molybdenum sheet appear attractive. The higher coefficient of expansion of tantalum than molybdenum (7.5×10^{-6} in./in. ° C for Ta; 5.0×10^{-6} for Mo) might be utilized in riveting since the tantalum should be expected to completely fill the hole during elevated temperature service. Miller[18] has reviewed the techniques for riveting molybdenum sheet. No literature is available for making folded seams (as in the tin can) in molybdenum. A mechanical joint might also be welded or brazed after mechanical joining.

In the next part of this paper experiments are described which permit a comparison of the various methods of joining molybdenum. The final section of the paper includes a discussion of the results based on our present knowledge of the relation of mechanical behavior of molybdenum to metallurgical prehistory.

EXPERIMENTAL RESULTS

Fusion Welding

In a previous report[19] results for atomic hydrogen fusion welds using tungsten and carbon electrodes were described. Bend test data were also given which included inert-gas-shielded tungsten-arc welds in air, in helium in an enclosure, and in a vacuum-tight apparatus using vacuum arc-cast molybdenum of high purity. Suffice to say the only fusion weldments that showed any semblance of ductility were of highly purified material. Even such welds did not show any tensile ductility at room temperature. Fractographic examination of all of the weld fractures made revealed the presence of grain boundary oxides, and in wrought vacuum cast material, carbides in the grain boundaries. Every fracture appeared to have an intergranular origin. In this study oxygen, whether from contained oxide or from the atmosphere, appeared to be the most harmful embrittling agent.

Butt-Joining Experiments

The lack of success with fusion welding led to a research program on butt joining. In this program, joining of molybdenum in various atmospheres such as

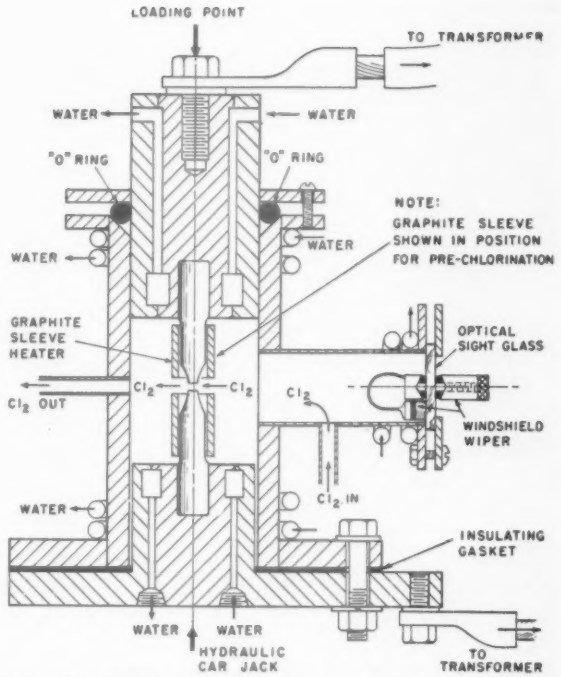

Fig. 1 Butt welding jig

hydrogen, helium, chlorine and carbon tetrachloride was carried out at temperatures above 900° C in special gastight apparatus. This was followed by similar experiments in air with "wash" atmospheres. Some of these experiments were repeated using high-frequency heating in a flowing gas stream with and without filler or brazing materials. The apparatus used for controlled atmosphere butt joining is shown in Fig. 1. It was constructed so that it could be evacuated and also filled with such corrosive atmospheres as chlorine. As shown in Fig. 1, the butt-welding press consists of a gastight, water-cooled cylinder containing two water-cooled pistons, one of them insulated electrically from the cylinder. Both pistons have alignment holes in them to receive the butt ends of the weld samples. A sight tube with window scraper was intended to enable the observer to measure temperatures. All parts are of monel metal for resistance to chlorine gas corrosion. A transformer, controlled separately by a Variac, permits heating of a graphite sleeve placed around the specimen for the low-temperature gas treatment of the surfaces to be joined. A second butt-welder transformer-Variac pair is used to heat the specimen itself for the second step, resistance butt welding.

To carry out a welding operation in this apparatus, the following procedure was used. The premachined specimen halves were assembled in the butt-welding chamber with a graphite sleeve between the shank ends as shown in Fig. 1. The graphite sleeve has optical-sighting holes and gas access holes drilled in it and performs the function of a heater while keeping the weld interfaces separated. Tank chlorine or other gas is introduced either by flushing, or by evacuating and filling.

Table 1

Pretreatment gas	*Temperature of graphite during pretreatment, ° C*	*Temperature of joint during joining, ° C*	*Gas*	*Tensile strength, psi*	*Remarks*
H_2	900	1000	H_2	23,800	.....
H_2	900	1100	H_2	43,400	Failure in joint
H_2	900	1100	Ar	28,000	.....
$MoCl_5$	900	1000	H_2	20,400	.....
Cl_2	1000	1000	H_2	52,400	.....
Cl_2	1025	1000	H_2	72,000	Failure outside weld
Cl_2	1025	1000	Cl_2	63,000	Failure in weld
Cl_2	950	1000	Cl_2	76,000	Failure outside weld
Cl_2	900	1300	Cl_2	40,000	Failure outside weld
Cl_2	1015	1400	Cl_2	No weld	Arc-cast Mo
Cl_2	1015	1600	Cl_2	66,500	Arc-cast—failure in weld
Cl_2	1015	1600	Cl_2	50,000	Arc-cast—failure in weld
CCl_4	900	1100	H_2	62,500	.....
CCl_4	900	1400	H_2	No weld	.....
CCl_4	No graphite	1800	CCl_4	49,000	Failure in weld
CCl_4	No graphite	1975	CCl_4	74,500	Transgranular failure outside weld
	No graphite				Some ductility
CCl_4	No graphite	1975	CCl_4	57,500	Transgranular failure outside weld
CCl_4	No graphite	1900	CCl_4	43,700	Arc-cast—transgranular failure in weld
CCl_4 (Ta insert)	No graphite	1975	CCl_4	74,500	Failure at Ta-Mo interface
CCl_4	No graphite	2000	CCl_4	75,000	Arc-cast—transgranular failure outside weld
CCl_4	No graphite	2100	CCl_4	81,000	Arc-cast—transgranular failure outside weld with some indication of plastic deformation

The temperature of the graphite is raised until copious blue-brown clouds of gas (in the case of chlorination) may be seen coming off the weld interfaces. This temperature was found to be about 300° C by auxiliary measurements made with a thermocouple with the chamber filled with helium instead of chlorine. Thermocouple measurements could not be made in chlorine gas due to the design of the system, and this constituted an exceedingly important uncontrollable variable. The time of prechlorination was thought to be of importance before the presence of nickel chloride was discovered.

After prechlorination the graphite sleeve was cracked off each time by squeezing the two specimen halves together. The weld region was then heated by passing a current directly through the interface between the two pieces, then in contact. Optical pyrometer readings could often not be made because of the clouds of condensed chloride in the chamber. This constituted the most important uncontrollable variable in the whole process, principally because prior current calibrations to produce a specific temperature were not at all consistent, and variations of ±50° C occurred.

The time and manner of application of pressure and heat were important, but a relatively standard manner was employed for applying pressure and amount of upset, by counting the number of hydraulic jack strokes. After welding, the upset weld specimen was machined to 0.200 in. diam x 0.5-in. gage length. Tensile testing of these specimens was done at a crosshead speed of 0.04 ipm at room temperature. The testing jig used prevents a bending moment from being developed at the weld interface of the specimen. The results are listed in Table 1.

Two kinds of molybdenum were used: Westinghouse powder-metallurgy molybdenum and heat No. 4929A of Climax vacuum-arc-cast carbon-deoxidized molybdenum. Physical properties of these two different grades of molybdenum are shown below.

	Ultimate tensile strength, psi	*Yield point, psi*	*Elongation in in., %*	*Reduction area, %*
1/2-in. Westinghouse powder-metallurgy molybdenum, annealed	76,400	74,000	9.2	11
Climax V.A.C. molybdenum, annealed, heat No. 4929A	91,000	82,300	26	29

Although some strong welds were made with powder-metallurgy molybdenum at 1000 to 1800° C, many more made in this temperature range could not even be tested. More consistent results were only achieved above 1800° C. At this stage of experimentation, it was decided to try similar experiments in a pool of carbon tetrachloride in air using a Thomson butt welder with a hydraulic ram and controllable upset speeds.

Butt Welding in Air

It is evident that in order to be usable industrially, any successful welding method must be done on commercially available machines with a minimum of alteration. In this series of experiments, such a technique has met with success, namely, room-temperature ductile weldments.

The butt welder used has a hydraulic ram with controllable upset speeds. For this application it was equipped with a solenoid timer calibrated to 1/4 sec. The bars to be welded were brought into bearing and maintained at pressure by bleeding a tiny stream of hydraulic oil by the solenoid valve. Initiation of the

welding current also initiated the timing-out period of the solenoid. Thus the time of current flow before application of forging pressure could be controlled to $\pm 1/4$ sec. This careful control of time of current flow was necessary to obtain reproducible temperatures at the moment of upset. Figure 2 shows the arrangements for making welds in a liquid medium.

Several heats of Climax vacuum arc-cast molybdenum and two heats of Westinghouse molybdenum were tried. In order to obtain the narrowest hot zone and consequently the greatest amount of upset in the region of the weld, the highest possible current-voltage settings were used. This requires particularly sensitive timing as a means of temperature control. In some cases lithium and sodium metal* were placed between the specimens immersed in carbon tetrachloride. A light preload of 100 lb was applied by means of a by-pass hydraulic line, and both current and timer turned on simultaneously. After a preset time (and presumably temperature, except for uncontrollable variations in surface resistivity) upset occurred and the current was shut off. This procedure produced ductile molybdenum weldments and was reasonably consistent. Welds were made in $1/2$-in. lengths of $1/2$-in. bar stock turned down to $5/16$ in. All tests were conducted in tension at 0.04 in./min crosshead speed on specimens machined after welding to 0.238 in. reduced diameter by 0.75-in. gage length.

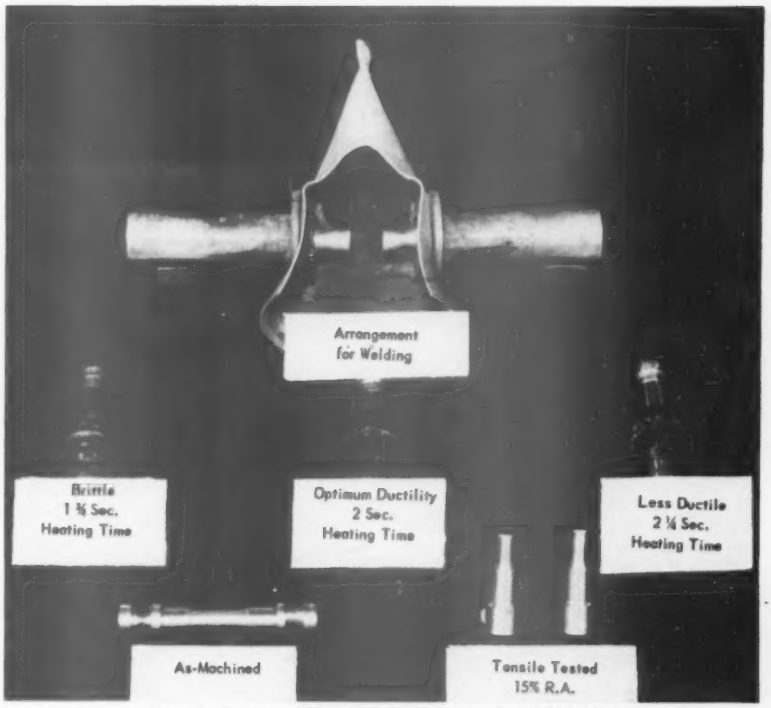
Arrangement for Welding
Brittle 1 ⅜ Sec. Heating Time
Optimum Ductility 2 Sec. Heating Time
Less Ductile 2 ¼ Sec. Heating Time
As-Machined
Tensile Tested 15% R.A.

Fig. 2 Butt-welding specimens and welding jig

All but the highest carbon content heats of Climax vacuum-arc-cast molybdenum were ductile. Maximum ductility was obtained in heat No. 4986-B1 at 0.036% carbon. Aluminum added during melting in place of carbon as a deoxidant did not improve as-welded ductility.

Two heats of powder-metallurgy molybdenum were available. One heat, of $1/4$-in. rod, exhibited ductility, the other, of $1/2$-in. rod, did not. The difference between these two heats may have been chemical, but it is more likely that the differences were due to primary fabrication differences arising from the fact that the $1/2$-in. rod does not represent a substantial reduction from the sintered ingot, whereas $1/4$-in. rod is more effectively hot- and cold-worked.

A correlation between the appearance of the as-welded upset and ductility was established. A very smooth rounded upset indicates a temperature too low to obtain ductility. An exploded fibrous upset indicative of the proper welding heat was consistently observed in ductile specimens. Upset that exhibited signs of fusion indicated too high a temperature. These qualitative observations are reproduced in Fig. 2. Figure 3 compares the macrosection of a joint made at too low temperature with one made at proper temperature.

Attempts to butt weld in air with lithium and sodium metal in the joint and in a wash of argon gas with lithium and sodium metal in the joint failed to produce a weld. It was likewise not found possible to achieve welds in a wash of argon or hydrogen without sodium or lithium. It was fortunately found possible to produce ductile welds in carbon tetrachloride and in water without the use of sodium and lithium.

The results obtained in air using carbon tetrachloride and water are listed in Table 2. Although the maximum tensile strength and percentage reduction in area were obtained when lithium and sodium were used in the joint, the joints made in carbon tetrachloride alone are much easier to make and quite acceptable. The joints made in water, though inferior to those made in carbon tetrachloride, are likewise of acceptable ductility. Wherever the temperature reached in joining was too high, brittle fracture was observed, but not in the weld itself. Whenever the temperature of joining was too low, brittle fracture occurred more often in the weld proper. All efforts to make direct measurements of the temperature reached at the faying surfaces during welding in carbon tetrachloride and water were unsuccessful.

Brazing

Flame brazing in air with an oxy-acetylene torch as

* Reagent grade; supplied by Mallinckrodt Chemical Co. and Foote Mineral Co., respectively.

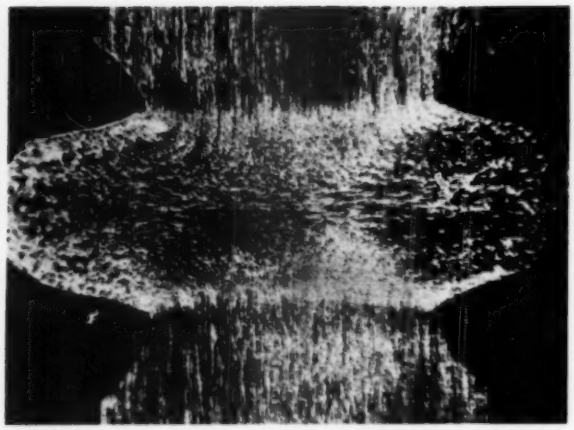

Fig. 3(a) Longitudinal section of brittle weld. ×8. Polished and etched

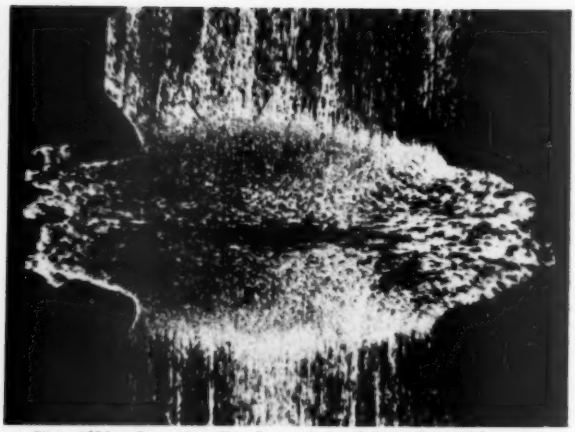

Fig. 3(b) Longitudinal section of ductile weld. ×8. Polished and etched

well as with an inert arc using various filler metals was soon abandoned due to the too rapid embrittlement of the molybdenum by this manner of heating. For this reason brazing in flowing argon or hydrogen or mixtures of the two was pursued in a Vycor tube furnace using high-frequency heating. The use of lap joint test specimens gave such a broad scatter of results that this method was abandoned in favor of butt brazing between 1/4-in. molybdenum rods. These were held in water-cooled grips in a press. A Vycor sleeve open at one end with a "T" connection covered the rods. A steady stream of pure argon or argon admixed with 10% H_2 was passed through the Vycor "T" tube at the rate of 350 lph. Heating was accomplished with a short 4-turn high-frequency coil about the joint. Before assembly, the brazing medium was placed as a foil or powder with or without flux on the lower specimen. Pressure was applied lightly until the joint came to temperature and then increased and maintained. After cooling the 3-in. brazed specimen was removed and

Table 2—Butt Welding of Molybdenum in CCl_4—Open Container

Procedure	*Material*	*Heating time, sec (x)*	*Yield point, psi*	*Fracture stress, psi*	*Reduction of area, %*	*Remarks*
50-lb preload, upset load applied by electric timer after *x* sec*	Climax No. 4986-B1 0.036% carbon	2 1/2	70,000	75,000	21	Brittle-ductile fracture
		2	72,000	90,000	45	Max % RA in weld metal—about 50% fibrous fracture
		1 3/4	76,400	85,000	28	About 30% fibrous
Lithium and sodium in joint with CCl_4 atmosphere		1 5/8	68,000	81,200	24	Failure outside weld
		1	...	40,500	0	.....
		3/4	...	28,500	0	.....
CCl_4 only, no sodium or lithium	Climax No. 4936-A 0.008% carbon	2 1/4	68,500	83,300	30	Fibrous fracture in weld
		2	73,600	83,600	27	Fibrous fracture in weld
		1 1/2	...	62,400	0	Brittle fracture
CCl_4 with sodium and lithium	Climax No. 4936-A, 0.008% carbon	2	74,300	83,500	24	Failure outside weld
	Climax No. 4938-A, 0.004% carbon (Al deoxidized)	2	62,000	72,500	13	Failure in weld
	Climax No. 4897-B2, 0.066% carbon	2	...	79,000	0.2	Failure in weld
	Climax No. 4929-A, 0.059% carbon	2	70,400	78,500	21	Failure in weld
CCl_4 with sodium and lithium	Westinghouse 1/4-in. rod, powder metallurgy	1	...	41,000	...	Considerable fusion (dimensions different than other samples)
		3/4	62,000	75,000	26	Fusion—failure in weld
		5/8	61,000	73,800	25	No fusion—failure in weld
		1/2	63,000	79,000	27	Failure in weld
		3/8	...	45,500	...	Same
CCl_4 with sodium and lithium	Westinghouse 1/2-in. rod, powder metallurgy	2 1/2	...	40,000	...	Brittle fracture in weld
		2 1/4	...	43,000	...	
		2	...	34,500	...	
		1 3/4	...	27,700	...	
		1 1/2	...	34,400	...	
		1 1/2	...	28,000	...	
		1	...	25,700	...	
Water alone	Climax No. 4986-B1	1 3/4	...	30,000	...	Brittle fracture in weld
		2	75,000	80,100	7.5	Fracture only partly fibrous
		2 1/4	...	72,400	...	Excessive fusion zone—brittle fracture

* Applies to entire series of tests.

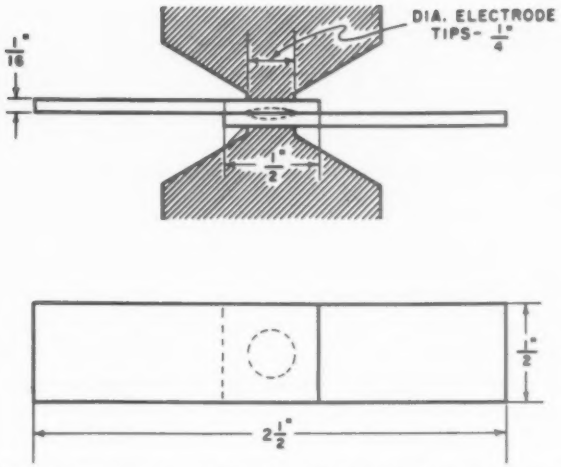

Fig. 4 Design of spot-weld specimen, single-spot lapped joint

ground to a diameter of 0.20 in. over a 0.50 in. gage length. It was then tested in tension at a crosshead speed of 0.04 ipm.

Some 150 samples were brazed. None exhibited any elongation in the tensile test. The majority of short-time brazes failed at the brazing metal : molybdenum interface. The long-time brazes failed either in the molybdenum itself or in the filler metal. Copper, which wets molybdenum admirably in hydrogen, required only slight application of pressure. Nickel, Monel metal and Nichrome, if not allowed to melt or produce a liquid phase during brazing, required a high pressure. Most other metals, especially those containing nickel, if heated to their melting point required little or no pressure. Only a limited number of examples are listed in Table 3 which are indicative of the best results obtained. A molybdenum-to-molybdenum joint made in the same pparatus without brazing media is also listed. Data are also included for bars which received the same heat treatment in the same apparatus as the welded specimens. Two specimens brazed, one with Cr and the other with Ti, are likewise included.

From the results of room temperature tests, it is evident that copper proved to be the best brazing medium. It is well to point out that Cu does not alloy with molybdenum. Chromium and titanium, which form solid solutions with molybdenum, alloyed completely with the molybdenum, and failed at a low stress level. Monel metal seemed to behave more akin to copper than to nickel or Nichrome. In both of the latter cases, the presence of intermetallic compound can be noted microscopically in the joint. Failure originates most readily in the band of intermetallic compound. In the case of Monel metal, no intermetallic compound was found in the joint.

Spot Welding

A 25,000-amp single-phase Thomas-Gibb Spot Welder controlled by a Westinghouse ignitron timer was used for these experiments. Three kinds of electrode tips were used to try to overcome sticking or welding of the molybdenum to the tips.

(*a*) Pure tungsten
(*b*) 49% tungsten, 50% copper, 1% nickel
(*c*) Pure copper

The copper tips were found to be satisfactory, but success in preventing sticking was achieved only by inserting lead foil between the tips and the molybdenum sheet. For experiments involving welding in carbon tetrachloride an open container to hold the carbon tetrachloride was mounted around the tips. The tips were machined to 1/4-in. diam flats.

Powder-metallurgy molybdenum sheet 1/16 in. thick was used for the lapped single-spot joints. Most of the sheet used was preannealed to just recrystallize the sheet. Specimen design is shown in Fig. 4. "Tensile shear" testing was conducted at a crosshead speed of 0.05 ipm.

Lead sheet was placed between the electrode tips and fused by resistance prior to each weld. After "leading" the tips, the spot weld was made.

Table 3—Butt Brazing Experiments in Argon-Hydrogen

	Joint	*Media*	*Flux*	*Temperature, ° C*	*Time at temperature*	*Final pressure of joining, psi*	*Tensile strength of joint, psi*	*Remarks*
1.	Mo to Mo	None	None	1675	20 min	6,000	61,500	Failure outside weld
2.	Mo itself	...	...	1675	20 min	...	68,600	Heat-treated control specimen. Elongation, 3%
3.	Mo to Mo	Cu 0.005-in. foil	None	1150	30 sec	1,000	73,000	Failure in Cu
4.	Mo to Mo	Cu 0.005-in. foil	KF	1150	30 sec	1,000	68,000	Dirty joint
5.	Mo to Mo	Ni 0.0007-in. foil	None	1200	10 min	15,000	64,000	Failure at Mo-Ni interface
6.	Mo to Mo	Ni 0.0007-in. foil	KF	1200	10 min	15,000	54,600	Failure at Mo-Ni interface
7.	Mo itself	...	...	1200	10 min	...	88,400	Ductile failure. Elongation, 16%
8.	Mo to Mo	0.002-in. Monel foil	None	1400	30 sec	1,000	75,500	Interface failure
9.	Mo to Mo	0.003-in. Nichrome foil	None	1400	30 sec	1,000	55,450	Failure in joint
			KF	1400	30 sec	1,000	56,500	Failure in joint
10.	Mo itself	...	...	1400	30 sec	...	88,600	Ductile failure. Elongation, 8%
11.	Mo to Mo	Electrolytic Cr powder	None	1700	1 min	5,000	32,000	Failure in weld
12.	Mo to Mo	Ti, hydride powder	None	1700	1 min	5,000	36,500	Failure in weld

Table 4—Spot Welding in Air and CCl_4

Material	*Nominal current, kiloamp.*	*No. of cycles*	*Load to failure, single spot*	*Remarks*
Single, spot lap weld	25	14	675	Failure adjacent to weld
Just recrystallized sheet, $^1/_{16}$-in. welded in air	23.75	14	595	Failure adjacent to weld
	22.5	14	645	Failure adjacent to weld
	21.25	14	25	Failure in weld
Same in CCl_4 with just recrystallized sheet	25	14	685	Failure adjacent to weld
	23.75	14	635	Failure adjacent to weld
	22.5	14	820	Failure in weld
	21.25	14	540	Failure adjacent to weld
With highly cold-worked sheet	22.5	14	360	Failure adjacent to weld and laminar
Same in CCl_4 with Na and Li	25	14	25	Pick up in joint
Same in CCl_4 with Na and Li	22.5	14	35	Pick up in joint
Same in CCl_4 with Na and Li	22.5	10	25	Pick up in joint
Same in CCl_4 with Na and Li	22.5	14	40	Pick up in joint
Same in CCl_4 with KF	22.5	14	45	Pick up in joint
Same in CCl_4	15	30	980	Failure at intermetallic compound interface
Ni foil 0.001-in. insert	15	30	880	Failure at intermetallic compound interface
Ni foil insert	15	30	860	Failure at intermetallic compound interface
Ni foil insert	15	30	720	Failure at intermetallic compound interface
Ni foil insert	22.5	14	40	Failure at intermetallic compound interface

The relative breaking strengths of the spot welded joints are listed in Table 4. Most of the failures occurred in the heat-affected zone adjacent to the weld. In severely cold-worked sheet, the failure in the heat-affected zone exhibited laminations. In only one case was failure in the weld observed in the straight molybdenum-to-molybdenum joints and that at a high breaking strength level. Of particular interest is the use of nickel foil which permitted welding to be carried out at a much lower temperature. The breaking strengths were on the average greater than any others measured. Failure appears always to be at the molybdenum-nickel interface. On metallographic examination, this interface was found to consist of an intermetallic compound layer. If this layer is too thick, as occurs when higher welding currents are employed, failure occurs at a much lower stress level.

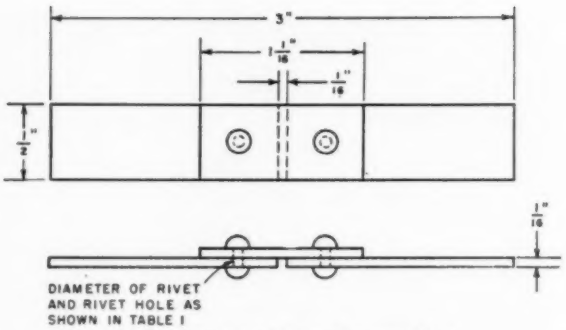

Fig. 5 Design of riveted assemblies

Riveted Joints

Design of the riveted structure is shown in Fig. 5. The holes were drilled rather than punched. Tensile testing was conducted at 0.04 ipm crosshead speed in the long direction of the specimen. Each size riveted specimen was made first with the apparent grain orientation parallel to the testing direction and secondly with this orientation perpendicular. Rivets were made by machining from Climax vacuum arc-cast molybdenum heat No. 4929A. The sheet material (heat No. 833-Al) was also Climax V.A.C. aluminum-deoxidized molybdenum and was known to be cross-rolled and annealed.

The assembled structure was placed in a butt-welding machine, and the temperature of the rivet brought up, between two flat copper blocks, to an estimated 700° C for upsetting. Since all failures occurred by rivet shear, the amount of upset is not important. Upsetting hot did not result in internal cracking parallel to the rolling direction of the rivets in this particular heat of molybdenum. During testing, reorientation of the rivets occurred in a direction such as to impose tensile stresses in the rivets, but no attempt was made to correct for this.

Table 5—Data on Riveted Joints

Rivet material	*Diameter of rivets, in.*	*Shear stress, psi*	*Type of failure*	*Remarks*
Mo	0.159	77,000	Ductile shear of rivet	
Mo	0.159	70,700	Ductile shear of rivet	
Mo	0.185	50,300	Ductile shear of rivet and crushed bearing	
Mo	0.185	55,000	Brittle fracture of sheet	Overheated during upset. Estimated temperature = 1500° C
Mo	0.125	87,600	Ductile shear of rivet	
Mo	0.125	...	Brittle fracture of rivet	Overheated during upset. Estimated temperature = 2000° C
Mo	0.096	82,800	Ductile shear of rivet	
Mo	0.096	81,200	Ductile shear of rivet	
Mo	0.059	Could not record	Ductile shear of rivet	
Mo	0.059	Could not record	Ductile shear of rivet	

Shear strengths obtained are shown in Table 5. All failures, except where noted with the reason, were ductile shear failures of the molybdenum or tantalum rivet.

DISCUSSION AND CONCLUSIONS

To introduce this discussion it is advisable to review some pertinent facts about the metallurgy of molybdenum. Annealing molybdenum above its recrystallization temperature but below 1950° C always results in embrittlement, in a matter of hours around 1000° C, but minutes or even seconds at substantially higher temperatures. However, ductility can be restored by plastically working the recrystallized metal. Annealing between 1950 and 2100° C spheroidizes the oxide in powder-metallurgy material, and in this range annealing results in considerable ductility. Above 2100° C eutectic melting of oxide impurities again embrittles the metal. In the case of carbide, all this occurs at a somewhat higher temperature.

The significance of these metallurgical facts can best be illustrated by considering the fusion and heat-affected zones in a joint in commercial molybdenum sheet, made by the best available fusion welding technique. Such technique may well result in a ductile fusion zone.[20] But adjoining this zone is the >2100° zone, in which eutectic melting occurs in seconds at temperature. This embrittled zone can only be avoided by using laboratory-pure parent metal or perhaps metal deoxidized with something other than carbon.[3] In most cases with commercial metal, we can also expect more or less embrittlement in the <1950° zone, although possibly with high-speed welding techniques this zone can be self-quenched before substantial embrittlement occurs.

Pursuing this line of thought further, it becomes apparent that joining processes conducted below 1950° C, e.g., brazing and pressure welding, depend for their success not only on proper control of the conventional welding variables, but also on devising means to minimize time above 900° C. Molybdenum is by no means unique in this respect. The processes by which bonding occurs, capillarity in the case of brazing and surface deformation in the case of pressure welding, are not time-dependent in the same sense as the metallurgical processes by which a joint deteriorates. Thus even such simple processes as copper-brazing or spelter-brazing of steel will give inferior joints if held too long at temperature.

This reasoning is best pointed up by considering pressure butt welding. Only limited success is obtained in the long-time, low-temperature experiments conducted in the chamber, despite meticulous precautions for cleaning, fluxing and atmospheric protection. Similarly, pressure welding in vacuum gives limited success even with laboratory-grade, purified molybdenum.[21] However, pressure welds of nearly parent-metal ductility are made in the commercial butt-welding machine. Here the precautions against contamination were most rudimentary; routine grinding of the faying surface and immersion during welding in a liquid medium, water or carbon tetrachloride, for the dual purpose of fluxing and quenching the joint. The success of the process is based on control of the key metallurgical variables: (1) Careful regulation of peak temperature to ensure a temperature high enough for adequate forging of the eutectic-embrittled zone, but without excessive fusion at the interface. (2) Minimizing time at temperature to minimize metallurgical damage in the recrystallization-embrittled zone. (3) Fast, extensive upset to ensure adequate forging of the former zone and possibly some beneficial deformation in the higher-temperature regions of the latter zone.

The butt-welding technique, properly applied, can give a high degree of ductility. However, the metallurgical reasoning just outlined indicates that percussion welding would be even more successful. Here the time at temperature is reduced to an absolute minimum, and the process can give extensive forging of the minute heat-affected zone. The liquid medium could certainly be dispensed with from a quenching standpoint, and probably also from a fluxing standpoint. Flash welding should also be potentially successful, if the flashing period can be kept short. Apparatus for testing these processes was not available in our laboratory, and they deserve further attention.

Spot welding should be considered apart from the other resistance welding processes. It is essentially a process in which a weld nugget is melted and recast *in situ*. The major function of the welding pressure is to confine this nugget during melting and freezing. The forging action is secondary in importance. As a matter of fact extensive forging with accompanying excessive indentation is considered commercially poor practice. Even where acceptable it forges only the metal between the electrodes, leaving the important zone around the nugget essentially undeformed. For purposes of comparison, it should be pointed out that, as a result, our best spot welds have only about one-half the strength of similar-size welds in mild steel. It is possible that double-projection welding, i.e., spot welding between projections on both faying surfaces, could combine the necessary forging action with a short time at temperature. Along the same line, a lap joint might be designed for percussion welding between carefully prepared projections.

The brazing processes show some promise for limited applications. Cold strength in a number of cases was good, but it is doubtful whether adequate hot strength and cold toughness can be combined in the same filler alloy. Thus copper brazing can be conducted quickly at low enough temperature so that parent-metal embrittlement is avoided. An excellent bond is obtained, but there is no alloying in this system, so strength above its melting point should be nil. A nickel joint will have better hot strength, but the time-temperature cycle necessary for furnace brazing with nickel embrittles the parent metal. Futhermore, wetting with nickel is slow, and considerable brittle intermetal-

lic phase is formed. Thus even if the recrystallization temperature of molybdenum can be raised by alloying, embrittlement of the molybdenum-nickel interface can be anticipated.

None of the brazed joints showed ductility. However, the tensile ductility of a butt-brazed joint has no meaning when the filler alloy has a lower flow strength than the parent stock. Analysis by plasticity theory shows that failure will occur when the yield strength of the parent stock is reached. The failure may be accompanied by extensive plastic flow in the filler alloy, but this will not produce measurable elongation of the over-all assembly. Thus bend and impact tests would be better for evaluating toughness of a brazed joint.

Spot or seam welding with a nickel interlayer is, in a sense, a brazing process. As compared to conventional welding, it has the advantage of very short heating time. Molybdenum sheet has been clad with Nichrome, using an interlayer of nickel foil or electroplate, with considerable success.[22] These specimens showed adequate bend ductility, despite the undoubted presence of a thin brittle intermetallic layer. Seam welding of dissimilar metals can, by careful current-time-pressure control, be applied as a true brazing process, with no fusion of the higher-melting metal.[23]

Riveting, because of its great flexibility from the standpoint of metallurgical control, is by no means out of the picture as a joining process for molybdenum sheet. The rivets may be of molybdenum, since adequate forging is obtained during heading. Or other rivet materials may be selected for specific applications. In either case proper technique will protect the parent stock from overheating.

In general then, joining methods in molybdenum depend for their success on minimizing metallurgical damage in the heat-affected zone. This is best accomplished by short times at temperature and extensive deformation of overheated regions. Since the causes of metallurgical deterioration inside the metal are as important as those from external sources, any joining method that provides external protection at the expense of speed is a step in the wrong direction.

A successful process is described, based on this approach, and fruitful directions for further work are suggested.

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Determination of Ferrite in Type 347 Stainless Steel Weld Deposits

The minimum amount of ferrite necessary to produce fissure-free weld deposits is difficult to define and hence a method of determining amount of ferrite in stainless steel weld deposits is important

by Walter L. Fleischmann

Abstract

The ferrite content of four Type 347 stainless steel weld deposits was determined by magnetic measurements using permeameter, "Magne Gage" and metallographic examination. To ascertain the ferrite content by a magnetic measurement it was necessary to compare the results at the level of magnetic saturation. At low magnetizing forces the magnetic induction was affected by particle size; thus a lower ferrite content was assumed than was actually present.

The chemical composition of the weld deposit depends upon the arc conditions. Therefore the calculation of the ferrite content by means of the nickel and chromium equivalents of Schaeffler is a function of the technique used by the operator. It also appears that nitrogen should be included in the group of elements used to establish the nickel equivalent and that allowance should be made for the weaker carbide-forming tendency of tantalum rather than applying the columbium equivalent.

A plot of percentage of ferrite vs. intrinsic induction at saturation results in a fairly straight line relationship for the four weld deposits.

INTRODUCTION

TO OBTAIN a crack-free or fissure-free Type 347 (18 chromium – 8 nickel – 1 columbium) weld, the chemical compositions of electrode and filler wire are adjusted to produce a deposit in which some ferrite is present within the austenitic matrix. The minimum amount of ferrite necessary to produce fissure-free deposits is difficult to define as fusion passes may sometimes require an electrode which gives a higher ferrite content in the deposit to offset the dilution from a strongly austenitic base metal.

There are, however, applications in which it is desirable to limit the ferrite content in the deposit to a low value. Welds in high-temperature installations should have a low ferrite content to minimize the embrittling effect of the sigma phase formed by the transformation of ferrite upon prolonged exposure to elevated temperatures. Another application for an austenitic weld deposit low in ferrite is in machinery which requires nonmagnetic materials.

The widely used ASTM-AWS electrode specification (ASTM Designation A298–48T; AWS Designation A5.4–48T) does not attempt to achieve any balance of austenite- and ferrite-forming elements. It simply states the minimum percentage of alloying elements that must be present in the weld deposit and the tensile requirements of an all-weld metal test bar that must be met in the as-welded condition. The military specification MIL-E-16715 (Dec. 21, 1951) goes one step further, insisting on minimum tensile ductility of a tensile specimen after a sigmatizing heat treatment, thus limiting the possible ferrite content. The possibility of an overly austenitic deposit is avoided by limiting the size of tears which may occur in a bend test to $^1/_{16}$ in the as-welded and heat-treated condition.

The Type 347 electrode specifications of the General Electric Co. (GE Specification B21B30) attempts to to control the ferrite content by setting a definite chromium to nickel ratio of 1.9 to 1. Recently an AWS filler wire specification was proposed which also has adopted the requirement of a chromium to nickel ratio.

The establishment of the ferrite content of an austenitic weld deposit is difficult. Metallographic examination does not yield an unqualified answer as the deposit is fine-grained, requiring high magnification on the microscope. Also, its structure is not uniform because each underlying layer receives a thermal treatment by the successive weld pass. The Schaeffler diagram[1] is generally used for calculating the ferrite content from the chemical composition (Fig. 1). However, the calculated amount of ferrite can be in error by ±2% ferrite.

The average Type 347 electrode lays down a weld deposit of about 7% ferrite. Variations to a low value of 5% or a high value of 8% are not considered significant.[2] However, if a low ferrite content is required,

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say not to exceed 4%, close control is required in order to assure the presence of a small amount of ferrite.

In order to determine what tests would give quantitative results for establishing the ferrite content, it was necessary to (1) study the spread of ferrite contents in individual lots of Type 347 electrodes and (2) evaluate possible test methods which allow measurement of the ferrite content and yield reproducible results.

Accurate determination of the ferrite concentration is also of interest for a study of possible phase changes occurring during heat treating or after extended service at elevated temperature in air or in a nuclear radiation field.

Because changes in ferrite content affect the magnetic behavior of the austenitic alloys, an investigation of the d-c magnetization curves of Type 347 weld deposits was considered to have the best prospects of yielding results. "Magne Gage" readings were also included to determine whether this inexpensive test would give parallel data which would obviate the complicated determination of ferrite by standard magnetic test methods. The results of those two studies were then compared with the microstructure. Electrical resistivity measurements were added to check for possible variations which may occur in identical weld deposits. Finally, since the control of the ferrite content is based on the composition of the wire and coating, chemical analyses of the investigated weld deposits made by two independent laboratories are reported here. A brief study of effect of the deposition procedure on the composition of the deposit was included to explain differences in the results of the analyses reported by the two laboratories.

EXPERIMENTAL PROCEDURE

For this test program, d-c type electrodes (lime-coated), $^5/_{32}$ in. in diameter, were obtained from one vendor in four chemical compositions within the Type 347 stainless steel composition range. The chemical compositions of the weld deposits laid down by these electrodes, identified by the letters A, B, C and D, are listed in Table 1.

Table 1—Composition of Deposit from Type 347 Electrodes, %

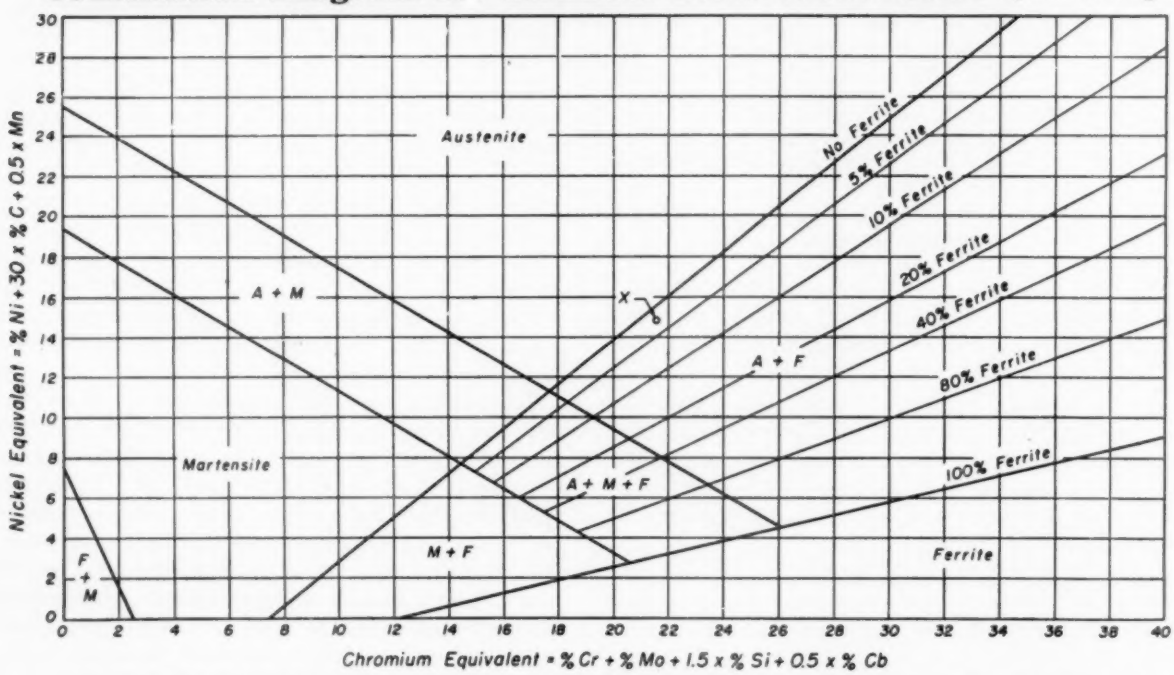
(D-C type, lime coated. Analysis as reported by vendor)

	Electrode			
	A	*B*	*C*	*D*
Carbon	0.064	0.07	0.09	0.08
Manganese	1.60	1.63	1.52	1.41
Sulfur	.....	0.01	0.01	0.009
Phosphorus	.....	0.013	0.009	0.013
Silicon	0.42	0.48	0.49	0.29
Nickel	9.64	10.64	11.53	12.74
Chromium	21.38	20.72	20.64	19.83
Columbium	0.92	0.86	0.80	0.89

All weld metal test specimens were machined from deposits which were laid down as multipass welds 1 in. high. The deposits were made on 36-in.-long bars of

Constitution Diagram for Stainless Steel Weld Metal

By Anton L. Schaeffler



EXAMPLE: Point *X* on the diagram indicates the equivalent composition of a Type 318 (316Cb) weld deposit containing 0.07% carbon, 1.55% manganese, 0.57% silicon, 18.02% chromium, 11.87% nickel, 2.16% molybdenum and 0.80% columbium. Each of these percentages was multiplied by the "potency factor" indicated for the element in question along the axes of the diagram, in order to determine the chromium equivalent and the nickel equivalent. When these were plotted, as point *X*, the constitution of the weld was indicated as austenite plus from 0 to 5% ferrite; magnetic analysis of the actual sample revealed an average ferrite content of 2%.

For austenite-plus-ferrite structures, the diagram predicts the percentage ferrite within 4% for the following stainless steels: 308, 309, 309Cb, 310, 312, 316, 317 and 318 (316Cb).

Fig. 1 Constitution diagram for stainless steel weld metal

Type 304 stainless steel. An interpass temperature of 300° F (150° C) maximum was maintained. The current (d-c reverse polarity; work negative) was approximately 150 amp. Each deposit was represented by 18 specimens (3.00 in. long, 0.250 in. diam) which were machined out of the center of the 1-in.-thick weld deposit. This rather large number of samples of each deposit was considered necessary to establish the possible spread of data in each group.

Electrode A was taken from the electrode manufacturer's stock and represents commercial manufacture. The columbium addition was made as usual to the coating in the form of ferrotantalum-columbium. Electrodes B, C and D were specially prepared. To minimize the number of variables, core wire from one heat of steel was used in these three lots. To obtain the variation of ferrite content in the deposit, nickel powder was included in the coatings of lots C and D, thus making their deposit increasingly austenitic. The columbium addition in these three batches was of the low tantalum grade.

The commercial weld deposit A had a ferrite content of about 10% according to the Schaeffler diagram. Electrodes B, C and D were ordered to yield deposits of about 7, 2 and 0% ferrite.

MAGNETIC PROPERTIES

Austenitic weld deposits become increasingly ferromagnetic as the concentration of ferrite increases. Tests methods for measuring magnetic properties have been well established. The maximum permeability and induction at saturation are employed to describe the percentage of ferrite present in the alloy. To determine these numbers, d-c magnetization curves of the four weld deposits (A, B, C and D) were taken from low to high magnetizing forces (50 to 6000 oersteds).*

The initial part of each magnetization curve was determined on a General Electric Low Mu Permeameter at magnetizing forces ranging from 50 to 300 oersteds. This part of the test was conducted in accordance with Method No. 1 of "Standard Methods of Test for Feebly Magnetic Materials" (ASTM Test Designation A342–49) with the exception that the length-to-diameter ratio was not, as generally required, 20 to 1 but instead was 12 to 1. However, from prior experience the error introduced by the smaller length-to-diameter ratio was known to be insignificant; in the range of permeability below 1.1 a ratio of 4 to 1 is even permissible.

For the larger magnetizing forces (400 to 6000 oersteds) the Sanford-Bennett High "H" Permeameter[3] was employed with a B coil length of 1.0 cm.

The initial po f the d-c magnetization curve was taken on all specimens. As the spread of results started to diminish at higher magnetizing forces (H = 300 oersteds), it was decided to limit the measurements

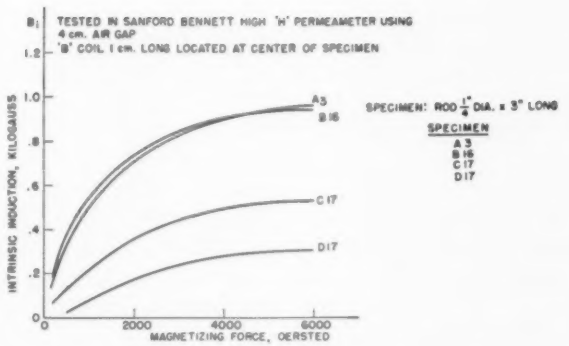

TESTED IN SANFORD BENNETT HIGH 'H' PERMEAMETER USING
4 cm. AIR GAP
'B' COIL 1 cm. LONG LOCATED AT CENTER OF SPECIMEN
INTRINSIC INDUCTION, KILOGAUSS
MAGNETIZING FORCE, OERSTED
SPECIMEN: ROD 1/4" DIA. x 3" LONG
SPECIMEN
A 3
B 16
C 17
D 17

Fig. 2 D-C magnetization curves. Four Type 347 stainless steel weld deposits

at higher magnetizing forces to only one specimen of each group (Fig. 2). However, to be able to compare the spread at saturation induction in the region of maximum permeability, all specimens were tested at 6000 oersteds.

ELECTRICAL RESISTIVITY TEST

Because electrical resistivity is a readily measured property which might reveal nonuniformity between samples of each group, the resistivity of each specimen was determined in accordance with ASTM Test Designation A344–49.

"MAGNE GAGE" TEST

The determination of the d-c magnetization curve is relatively complicated, and equipment for such a test is not generally available. Therefore, it appeared advantageous to test these weld deposits with the "Aminco Brenner Magne Gage," an inexpensive instrument which was developed to determine the thickness of nonmagnetic coatings on magnetic materials. This instrument measures the force required to break the hold of a standard permanent magnet from the specimen. From calibration curves, this force can be converted to an approximate value of ferrite content. The ferrite percentage as measured by the Magne Gage was obtained from tests with the No. 4 magnet.† The particular magnet used in this investigation was calibrated with plastic compounds containing varying percentages (volume) of carbonyl iron powder so that the force required to break the hold could be converted to a definite percentage of ferrite.

Because it is not obvious that a calibration curve based on the attraction of a given magnet to carbonyl iron compacts is a valid measure of the attraction of the same magnet to a different material (that is, highly alloyed ferrite in an austenitic matrix), carbonyl iron compounds were prepared so that their d-c magnetization curves could be compared with those obtained on the four weld deposits.

* The d-c magnetization curves reported in this paper were taken in the General Engineering Laboratory of the General Electric Co. by S. J. Burimaukas under the direction of A. E. Kettner.

† The Magne-Gage tests were performed by Leo Satz, formerly with the General Engineering Laboratory of the General Electric Co., now with the Knolls Atomic Power Laboratory.

Table 2—Comparison of Chemistry of Different Weld Deposits Made with Identical Electrodes

	Laboratory	*C*	*Mn*	*S*	*P*	*Si*	*Ni*	*Cr*	*Cb*
A	Vendor	0.064	1.60	...	...	0.42	9.64	21.38	0.92
	KAPL	0.066	1.60	0.029	0.025	0.40	9.74	20.4	0.71
B	Vendor	0.07	1.63	0.01	0.013	0.49	10.64	20.72	0.86
	KAPL	0.06	1.60	0.01	0.008	0.34	10.44	19.91	0.91
C	Vendor	0.09	1.52	0.01	0.009	0.49	11.53	20.64	0.80
	KAPL	0.05	1.61	0.01	0.007	0.36	11.22	19.67	0.88
D	Vendor	0.08	1.49	0.009	0.013	0.29	12.74	19.83	0.89
	KAPL	0.092	1.61	0.006	0.009	0.43	12.49	19.84	0.99

Table 3—Effect of Welding Variables on Chemical Composition of Weld Deposit of Electrode B

Operating condition	*C*	*Si*	*Ni*	*Cr*	N_2
1/8-in. arc length, 155 amp	0.055 0.052	0.31	10.52	20.19	0.118
1/8-in. arc length, 125 amp	0.063 0.065	0.38	10.39	20.27	0.068
1/8-in. arc length, 155 amp	0.072 0.070	0.44	10.34	20.22	0.034
1/8-in. arc length, 125 amp	0.075 0.071	0.45	10.34	20.29	0.040
Tolerance	±0.002	±0.02	±0.1	±0.4	±0.002
Vendor's analysis	0.07	0.48	10.64	20.72	...
KAPL'S 1st analysis	0.06	0.34	10.44	19.91	

Table 4—Chromium and Nickel Equivalents Calculated in Accordance with Schaeffler's Data and Per Cent Ferrite Content from Fig. 1

	Vendor analysis			*KAPL analysis*		
Electrode deposit	*Cr Equiv.*	*Ni Equiv.*	*Ferrite, %*	*Cr Equiv.*	*Ni Equiv.*	*Ferrite, %*
A	22.47	12.06	13	21.20	11.52	12
B	21.87	13.55	7	20.88	13.04	6
C	21.77	14.99	3	20.63	13.52	4
D	20.83	15.89	0	19.99	16.04	0+
B, 1/8-in. arc length						
155 amp	...	...	..	21.01	12.97	7
125 amp	...	...	..	21.30	12.99	8
B, 1/8-in. arc length						
155 amp	...	...	..	21.34	13.24	6
125 amp	...	...	..	21.42	13.30	6

Table 5—Ferrite Content of Weld Deposits Obtained by the Use of Campbell and Thomas' Chromium Equivalency

(Chromium, 2.5 × silicon, 2 × columbium)

Weld deposit	*Chromium equivalent*	*Nickel equivalent*	*Ferrite, %*
A	24.00	12.4	15
B	22.96	13.2	12
C	22.64	15	5
D	22.63	16	1

To include the effect of grain size, two series of artificial compacts were molded into lucite bars (1/2 x 1/2 x 5 in. long) which contained 1/2, 2, 5, 10 and 20% carbonyl iron in 3 and 20 micron powder size. The magnetization curves for these samples are given in Figs. 3 and 4. The negative slope of the B_i-H curves at magnetizing forces greater than 6000 oersteds is a

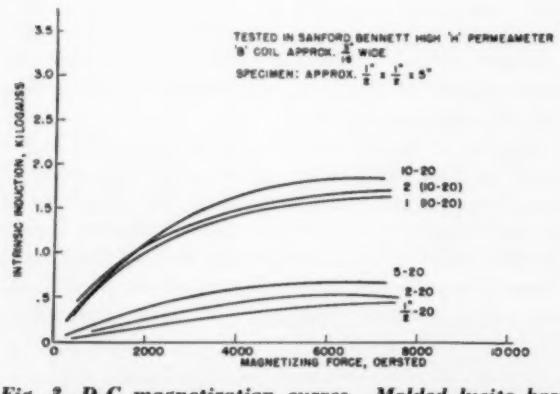


Fig. 3 D-C magnetization curves. Molded lucite bars with various percentage dispersions of carbonyl iron (20 microns)

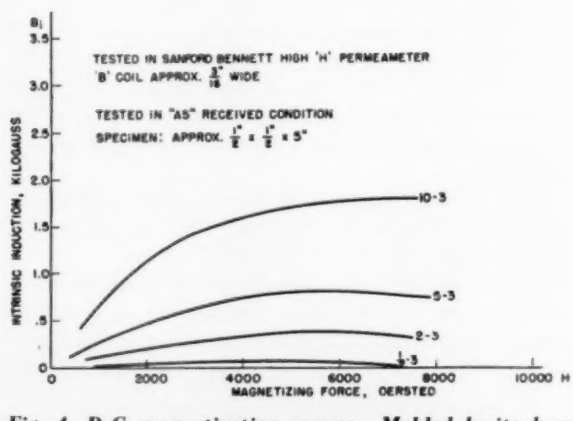


Fig. 4 D-C magnetization curves. Molded lucite bars with various percentage dispersions of carbonyl iron (3 microns)

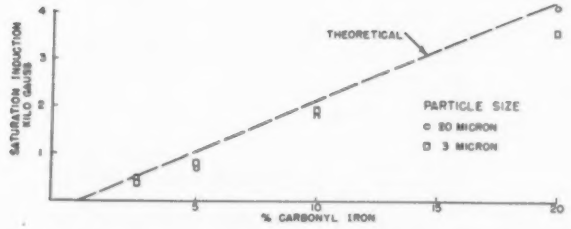


Fig. 5 Saturation induction of carbonyl iron compacts of varying iron content in relation to theoretical saturation induction

characteristic of the permeameter when testing weak magnetic compounds.

Figure 5 shows the measured maximum induction of the compacts plotted vs. the intended ferrite percentage. The theoretical maximum induction is also given so that the accuracy of the compacts can be judged.

CHEMICAL COMPOSITION

The ferrite content of the as-welded deposit is primarily dependent upon the chemical composition, though cooling rates which are controlled by interpass temperature, heat input and section thickness will have a secondary effect. It is important, therefore, to know how closely the results of chemical analyses made on different welds, deposited with identical electrodes but by different operators, will agree.

Table 2 shows the composition of the deposits as reported by the vendor and the check analyses made by KAPL on welds deposited under normal operating conditions. In general, there is good agreement except in the carbon and silicon values.

As welding conditions may have an influence on the composition of the deposit (recognized by ASTM in the applicable specification ASTM A316–48T), deposits were made with electrode B under four different operating conditions: long arc (about $^1/_4$ in. length) and short arc (about $^1/_8$ in. length) and with currents of 155 and 125 amp. The interpass temperature was held to 300° F (150° C) maximum. Table 3 shows that the arc length controls the transfer of the readily oxidizing elements. Carbon and silicon is lower in the deposits made with the long arc than with those made with the short arc. The arc current in the investigated range does not contribute much to the variation of the composition of the weld deposits produced with the short and long arcs.

In Table 4 the ferrite content of the deposits is calculated in accordance with the Schaeffler diagram and the chromium and nickel equivalents are calculated from the available chemical analyses.

Assuming that the Schaeffler diagram gives a true picture of the constitution of austenitic weld deposits, the agreement between the requested ferrite contents of deposits B, C and D (7, 2 and 0%) and those calculated from the composition of the actual deposits is excellent. However, it should be noted that welding conditions affect the chemistry and, consequently, the ferrite content of the deposit. In the case of weld deposit B, a difference of about 2% can be calculated.

DISCUSSION OF RESULTS

Each of the preceding tests revealed differences among the ferrite concentrations of the four weld deposits. As the d-c magnetization curves which were obtained on the permeameters cover practically the complete range from low to high magnetizing forces, the results from the tests on the two permeameters will be used as the primary yardstick. The data from the Magne Gage check and the ferrite content calculated from the Schaeffler diagram will then be correlated with the d-c magnetization values.

In comparison of magnetic properties of materials, two terms are used which describe the character of the d-c magnetization curve. The first term—permeability—is the ratio of magnetic induction or flux density B to the magnetizing force H. In ferromagnetic materials the permeability is a nonlinear function of H. The particular value of permeability employed in evaluating the magnetic properties is the maximum permeability. It is that point on the B vs. H curve at which the slope is maximum. The other term is intrinsic induction B_i or B minus H at saturation. At this point an increase in magnetizing force does not cause an increase in intrinsic induction. In the slightly magnetic austenitic steels the maximum permeability occurs at low magnetizing forces. With increasing fields the permeability approaches one (Fig. 6).

Weld deposit D was an exception to that rule. It shows a slight increase in permeability under high

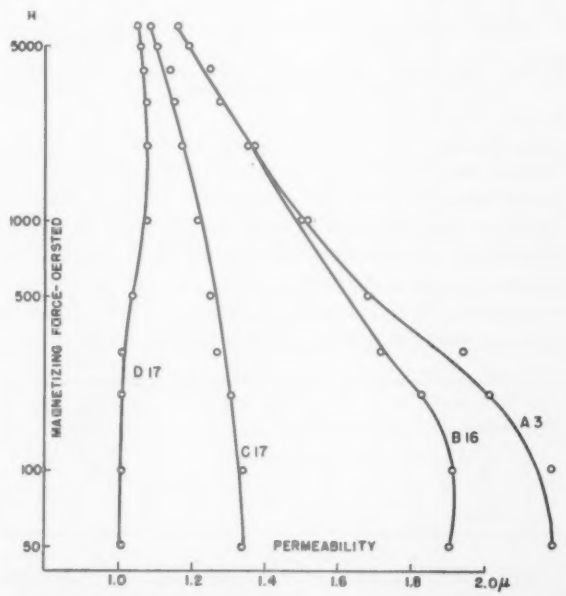


Fig. 6 Permeability vs. magnetizing force of Type 347 stainless steel weld deposits

magnetizing forces, probably caused by minute areas of ferrite subdivided by large gaps of the nonmagnetic austenite. The permeabilities of the individual specimens in the region of the low magnetizing forces show a considerable spread in the samples containing some ferrite. The reason for this behavior is that the maximum permeability, which in the slightly ferromagnetic austenitic steels occurs at the early part of the magnetization curve, is sensitive even to small changes in composition and to small variations in the thermal and mechanical history of the specimen.[4] At higher magnetizing forces the permeability values of specimens from each group converge as a result of saturation. At saturation (6000 oersteds) the differences in induction B of the samples from the individual lots are negligible.

The good agreement of the induction at saturation values in each group is paralleled by the extremely narrow spread of the respective electrical resistivity values. It is interesting to note that the change of resistivity in this limited range of alloys investigated appears to be a linear function of the nickel content (Fig. 7).

The Schaffler diagram gives the percent of ferrite as a function of the chromium and nickel equivalent.

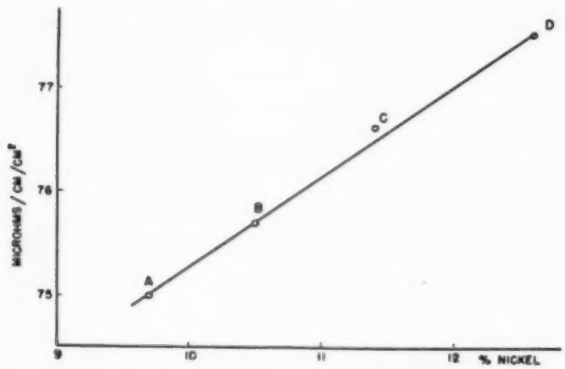


Fig. 7 Nickel content of four weld deposits (as-welded) vs. electrical resistivity

The diagram can also be drawn to show the ferrite content as a function of the nickel equivalent with the chromium equivalent as a parameter. The numerical values of the equivalents used in this figure were calculated from those chemical analyses which showed the highest carbon and silicon contents except in the case of deposit B where average values were chosen, taking into account the additional data from the special test.

Deposit	*Chromium equivalent*	*Nickel equivalent*
A	22.47	12.40
B	21.50	13.2
C	21.77	15
D	20.83	16

The ferrite content determined from the Schaeffler diagram as a function of the nickel equivalent is shown in Fig. 8 for chromium equivalents of 22 and 21.

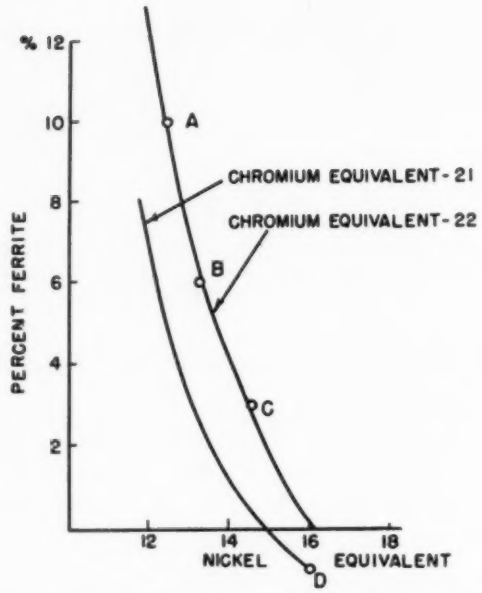


Fig. 8 Per cent ferrite as a function of nickel equivalent according to Schaeffler diagram,

By plotting the intrinsic induction at saturation (Fig. 9) and the permeability at 50 oersteds (Fig. 10) as a function of the nickel equivalent, several observations can be made. First, the magnetic properties of deposits B, C and D indicate a straight line relationship with the nickel equivalent. This fact is readily explainable as all three electrodes contain the identical core wire and the change in the ferrite content was brought about by nickel additions to the coating. Second, deposits A and B have about the same magnetic properties; this fact was not indicated by the data calculated from the Schaeffler diagram and shown in Fig. 8.

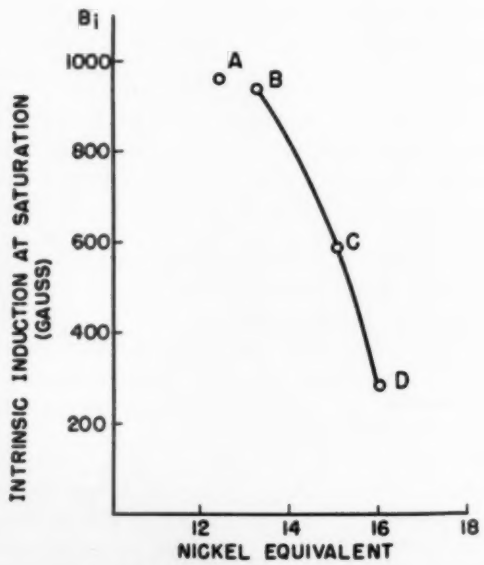


Fig. 9 Intrinsic induction at saturation as a function of nickel equivalent

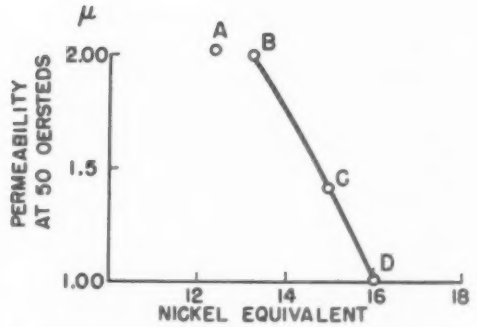


Fig. 10 Permeability at 50 oersteds vs. nickel Equivalent

The evaluation of the microstructures by point count arranges the microstructures in about the same order: weld deposit A—11% (Fig. 11*a*); B—12% (Fig. 11*b*); C—6% (Fig. 11*c*); D—not countable (Fig. 11*d*). The reversion of the ferrite contents of A and B is not surprising since, in evaluating the ferrite content by the metallographic method, the decision had to be made as to what constituted a representative structure. Rather arbitrarily, that structure of the weld deposit was chosen which appeared least affected by subsequent welding passes. Therefore, an interpretation of the point count of the microstructures indicates that weld deposits A and B had about the same ferrite content and weld deposit C lay about halfway on the scale between no ferrite content (weld deposit D) and a ferrite content of about 10 to 12% (weld deposits A and B).

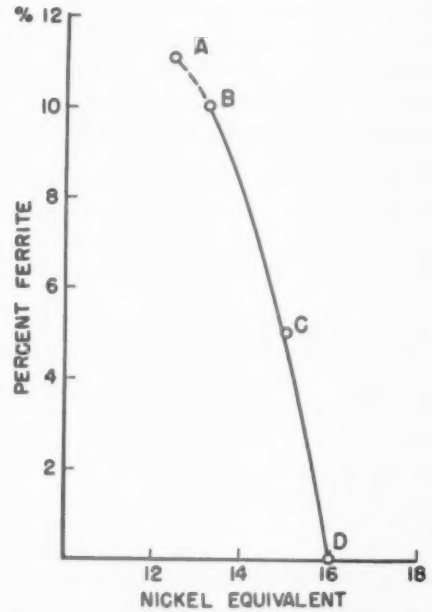


Fig. 12 Per cent ferrite ("Magne Gage") vs. nickel equivalent

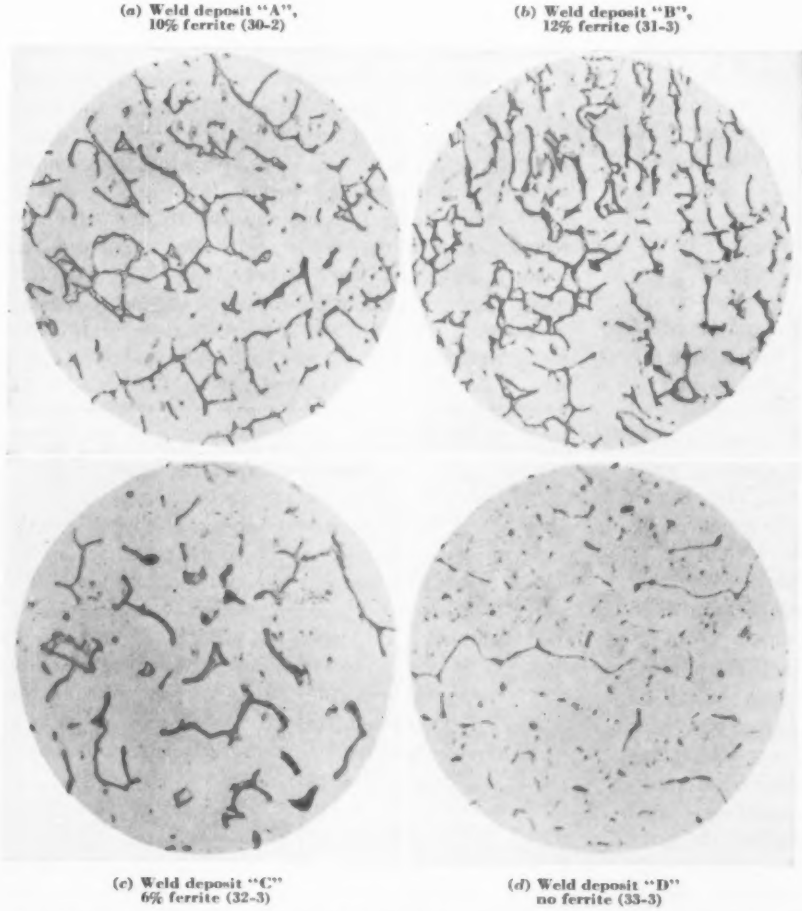


Fig. 11 Microstructures of Type 347 weld deposit. Etchant Kalling's reagent. Magnification × 1000, reduced 1/3 in reproduction

This result agrees well with the data from the Magna Gage (Fig. 12) and d-c magnetization tests which were represented as a function of the nickel equivalent, although it does not agree with the data obtained from the Schaeffler diagram. According to the Schaeffler diagram there should be considerable difference in ferrite content between electrodes A and B, which was not the case. The one reason which might explain this fact is that the stabilizing elements in electrode A are columbium plus tantalum. Therefore, tantalum should be taken into account, and since its carbide forming tendency is about one-half as effective as that of columbium,[5]

tantalum should not be rated as high a ferrite former as columbium. Hence the difference in chromium equivalents between A and B was not as great as had been calculated. The second anomaly in the data was the spread between the calculated data and the actual results on weld deposits B, C and D. Deposit D exhibited a slight amount of ferromagnetism at very high magnetic forces, although it should have been fully austenitic according to the Schaeffler diagram. Weld deposits B and C should also have had a lower ferrite content.

The formula originally used by Thomas and Campbell[6] to calculate the ferrite content employed a chromium equivalent in which silicon was rated at two and one-half its percentage and columbium at twice its percentage. At that time this equivalency was based primarily on experience with cast and wrought alloys. Some time later, after examination of many weld deposits, this ferrite-forming equivalency was modified by giving columbium one-fourth of the original rating and lowering the silicon equivalency to one and one-half its percentage. As at that time the a-c, d-c type of electrode was used, the results are probably correct for deposits made with those electrodes, which operate with long arcs. Under these long arc conditions, the deposit was more austenitic than the Campbell and Thomas equivalents predicted. Hence, the chromium equivalence was lowered by Schaeffler,[1] while the nickel equivalence was left unchanged. Among austenite-forming elements, however, nitrogen has been omitted in the nickel equivalency. Since under long arc conditions the opportunity for nitrogen absorption existed, probably the nickel equivalency should have been modified by including nitrogen and the chromium equivalency left unchanged. The tests on the effect of arc lengths on the composition (Table 3) supply some evidence for this assumption. Under long arc conditions with a heavy current, a considerable amount of nitrogen entered the arc atmosphere. With about the same arc length but lower heat input, nitrogen pickup was less than for the high heat input although it was 50% more than for the short arc conditions. Under short arc conditions the nitrogen pickup does not seem to be influenced by the arc current. The ferrite measurements here were made on deposits produced by lime-coated wires which were operated with a short arc. Therefore, less nitrogen pickup can be expected, and the deposits should contain more ferrite than Schaeffler's chromium equivalence indicated.

Using Campbell and Thomas values for the chromium equivalence, higher ferrite contents were found on Schaeffler's diagram; these data then agreed well with the test results. The nickel equivalency which appeared to correlate the data satisfactorily automatically included nitrogen in this test series, as lime-coated electrodes were used for all four deposits and the same welding procedure was used in the making of the weld deposits. Hence identical nitrogen contents can be assumed. Again, in the calculation of the chromium equivalent, no allowance was made for partial replacement of columbium by tantalum, although it would weigh much heavier in the old equation than in the Schaeffler equivalency.

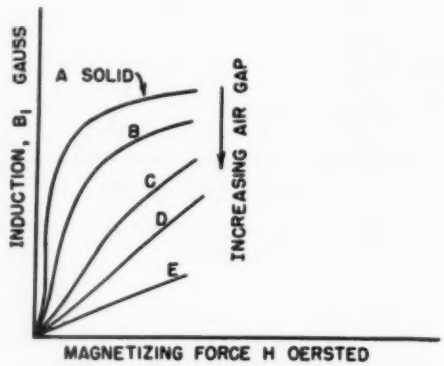


Fig. 13 Effect of air gap on the magnetization curve[7]

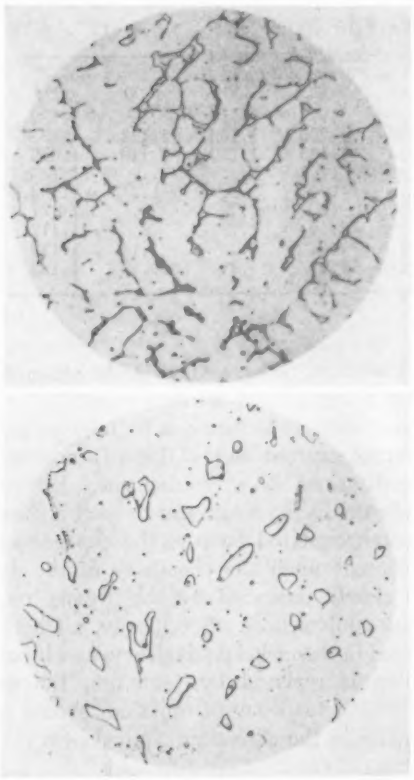
The results of the Magne Gage test arrange the ferrite content of the weld deposits in the same order as the results of the permeameter test. Strangely enough, the numerical values of ferrite content arrived at by the use of the carbonyl iron-lucite compound for standardization of the reading agreed very well with the ferrite content (Fig. 10) shown by the micrographs. The reason that the carbonyl iron compounds gave usable results not affected by the difference in magnetic properties between carbonyl iron and the alloy ferrites was the overriding effect of particle size, which, because of the many air gaps, produced a so-called "sheared magnetization" curve. This means that a larger magnetizing force is required to overcome the demagnetizing effect of the multitudes of air gaps to produce the same effective field (Fig. 13). The difference in the magnetic properties of carbonyl iron powder and alloy ferrites is marked at saturation induction (Table 6).

Table 6—Permeability at 50 Oersteds and Saturation Induction at 6000 Oersteds of Weld Deposits and Carbonyl Iron Standards

Sample	*Permeability at 50 oersteds*	*Saturation induction, 6000 oersteds*
Weld deposit A3	2.186	960
Weld deposit B16	1.897	945
10% carbonyl:		
3 micron	1.641	1760
20 micron	2.013	1840
Weld deposit C17	1.338	530
5% carbonyl iron:		
3 micron	1.303	660
20 micron	1.329	810
Weld deposit D17	1.007	310
½% carbonyl iron		
3 micron	1.018	60
20 micron	1.02	410
2% carbonyl iron		
3 micron	1.099	380
20 micron	1.103	520

To ensure that a single point value as obtained by measuring the ferromagnetism of the sample with one

(a) Weld deposit "A"
10% ferrite, as welded (30-2)



(b) Weld deposit "A", heat treated at 1900 F, 2 hrs, water quench

Fig. 14 Microstructure of Type 347 weld deposit. (a) As-welded, (b) as-welded and heat treated

specific magnet can replace a complete d-c magnetization curve, an additional test was indicated.

Two avenues of approach could have been chosen. One would have been to select a strong magnet to test the weld deposit at high flux densities approaching saturation. This was not feasible because the magnet would have to be standardized on a powder which had to have the same magnetic properties at saturation as the alloy ferrites. Such a powder was not available.

The other method was to change the structure of the weld deposit by a heat treatment which alters grain size and ferrite concentration and then compare the results of the d-c magnetization data with the Magne Gage results. Consequently, eight specimens of group A were given a solution treatment of 2 hr at 1040° C (1900° F) followed by a water quench (Fig. 14). These samples were then tested in the permeameters (Fig. 15) and by Magne Gage. The Magne Gage test places the ferrite content of the heat-treated sample at about 5%, just at the level of the C group. The permeability at 50 oersteds of those A samples was in the range of the C group. However, if the saturation induction is considered, the ferrite content of the heat-treated A samples is higher than that of the C samples. It can be concluded, therefore, that a comparison of ferrite contents of different weld deposits in all states of con-

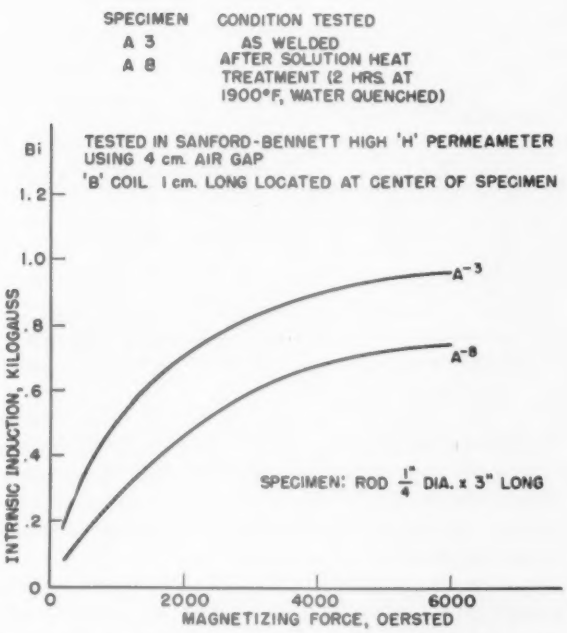


Fig. 15 D-C magnetization curves. Type 347 stainless steel weld deposits, as-welded and heat treated

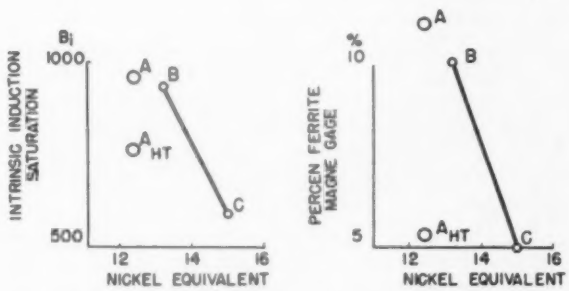


Fig. 16 Effect of heat treatment on magnetic properties, measured as saturation induction and by Magne Gage

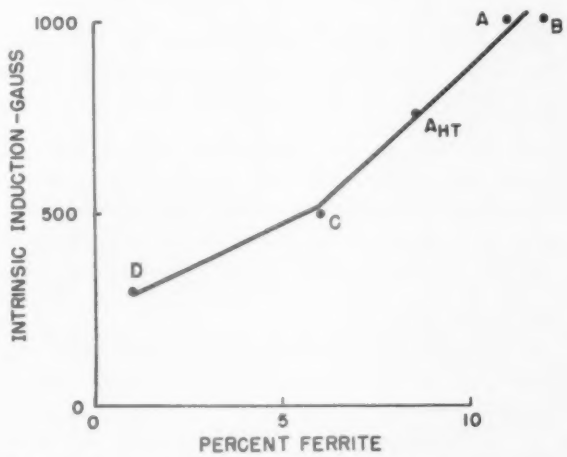


Fig. 17 Per cent ferrite determined from microstructure vs. intrinsic induction at saturation

ditions has to be made at saturation induction since, at low fields, grain size plays such a predominant role that not the ferrite content, but air gap, is measured

Table 7—Properties of Type 347 Stainless Steel Weld Deposit A

(Heat treated at 1040° C (1900° F) for 2 hr; water-quenched

Specimen A	GE-Low Mu Permeameter — Magnetic Permeability μ at H= 50	100	200	300	Sanford-Bennett Permeameter — Magnetic Permeability μ at H= 500	1000	2000	3000	4000	5000	6000	Magne Gage
7	1.348	1.348	1.323	1.302	..	...	...	...	...	...	1.132	5.0
8	1.333	1.326	1.304	1.285	1.32	1.270	1.230	1.200	1.168	1.143	1.123	5.5
C17*	1.338	1.338	1.305	1.271	1.22	1.220	1.175	1.145	1.120	1.110	1.085	4.5
9	1.478	1.456	1.406	1.372	..	...	...	...	...	...	1.132	6.0
11	1.290	1.297	1.279	1.261	..	...	...	...	...	...	1.132	4.0
12	1.333	1.333	1.311	1.292	..	...	...	...	...	...	1.127	5.0
14	1.319	1.311	1.286	1.266	..	...	...	...	...	...	1.112	5.0
15	1.377	1.377	1.344	1.319	..	...	...	...	...	...	1.132	5.5
18	1.363	1.363	1.337	1.319	..	...	...	...	...	...	1.132	6.5

* Magnetic test results on Specimen C17 inserted for comparison.

(Fig. 16). The ferrite content of the heat-treated sample decreased from about 11 to 8–9%. This evaluation was made by measuring the ferrite area with a planimeter. This method was chosen in preference to the line count because of the spheroidal shape of the ferrite.

A plot of the ferrite percentage versus intrinsic induction at saturation shows a fairly good linear relationship (Fig. 17). From this it appears that the magnetic properties when measured at high inductions are a reproducible measure for the ferrite content.

SUMMARY

The results of this investigation which was undertaken to establish a sound basis for determining the ferrite concentration in austenitic weld deposits were as follows:

1. The ferrite content in austenitic weld deposits cannot be accurately determined from the nickel and chromium equivalents established for locating the ferrite percentage in the Schaeffler diagram.

(*a*) The calculation of the nickel equivalent should include nitrogen.

(*b*) With consideration of nitrogen in the nickel equivalent, there were indications that the chromium equivalent established by Campbell and Thomas should be used.

(*c*) If ferro-tantalum-columbium is used, the tantalum equivalency should be adjusted because the equivalence of tantalum is one-half that of columbium.

2. To compare the chemistry of weld deposits, welding conditions have to be standardized since silicon, carbon and nitrogen are affected by the arc length and current.

3. The intrinsic induction at saturation gave consistent results and was not affected by the grain size of the ferrite phase.

4. Magnetic properties established at low fields were sensitive to grain size and were not, therefore, a good measure of the ferrite content in austenitic weld deposits.

5. As Magne Gage readings are made at low flux densities, changes in ferrite particle size affect the results. Therefore, Magne Gage tests are not recommended for determining ferrite content.

6. Saturation induction can be used as a measure of the ferrite content and, if desired, may be written into specifications as a requirement. However, difficulties in producing electrodes to such a specification might be encountered because the dependence of the ferrite content upon the chemistry of the deposit is not too closely described by the present nickel and chromium equivalences. Specifically, nitrogen should be included in the nickel equivalency, and if part of the columbium is replaced by tantalum, the decreased ferrite-forming tendency of tantalum should be taken into account in the chromium equivalency.

ACKNOWLEDGMENT

The data on which this report is based represent contributions from many members of the General Electric Co.

Dr. M. B. Reynolds of KAPL and Dr. C. P. Bean of the Research Laboratory reviewed the data and made many constructive suggestions. A. E. Kettner and S. J. Burimaukas of the General Engineering Laboratory and L. H. Satz, formerly with that division but now a member of KAPL, deserve special thanks for their efforts toward producing the excellent magnetic and "Magne Gage" data. Dr. L. P. Pepkowitz and J. L. Marley made the many chemical analyses which helped to clarify some of the variations occurring in analyses of weld deposits. The photomicrographs were prepared by J. W. Czarkowski. Special thanks are due to R. F. Koenig for encouraging this extensive study of the measurement of the ferrite content.

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Progress Report No. 7: Welded Continuous Frames and Their Components

Welded Portal Frames Tested to Collapse

Testing apparatus, measurement techniques and testing procedures for loading rigid frame structures through the plastic range to failure

by J. M. Ruzek, K. E. Knudsen, E. R. Johnston and L. S. Beedle

Abstract

The testing apparatus, measurement techniques and testing procedure for the investigation of the ultimate carrying capacity of welded portal frames are described. Two frames of uniform cross section (8WF40 and 8B13, respectively) were tested, the loading being carried through the plastic range to failure. Some typical results are given.

A method of providing lateral support to the frames and a simple device for measuring the change in curvature of structural members are presented.

INTRODUCTION

THE investigation of welded portal frames, the test equipment for which is described in this paper, is part of a current study of "Welded Continuous Frames and Their Components" being conducted at Lehigh University in the Fritz Engineering Laboratory. The research is sponsored jointly by Welding Research Council through the Lehigh Project Subcommittee of its Structural Steel Committee, and the Department of the Navy.

The objectives of the Lehigh study of welded structures are to determine the behavior of steel beams, columns, welded continuous connections and frames and, on the basis of this knowledge, to explore the possibilities of improved methods of analysis and design, due regard being taken of limitations such as large deflections, local and lateral buckling and fatigue.

Under this program, a study of the plastic behavior of wide flange beams was completed in 1948.[1] A program of tests of columns under combined thrust and moment commenced in 1946 under sponsorship of the American Institute of Steel Construction. The test equipment used in this study is described in an earlier paper.[2] The problem of connections for welded continuous portal frames is treated in three papers.[4]

Following these investigations of the component parts of continuous structures, full-size portal frames were tested. The principal purposes were:

1. To check the behavior of various frame components (such as connections, columns and beams) with the numerous isolated tests which have been performed.
2. To check actual deformations and internal forces with those predicted by various analytical treatments.

This report is a description of the testing apparatus used in the frame tests. Some representative test results are presented as typical examples of the data collected or to demonstrate the effectiveness of the equipment. In a forthcoming report the complete test results will be presented.

Testing procedures used in other full-scale frame investigations are reported upon in References 7 and 9–13, all of which list further references. Reference 7 also presents a survey of related research abroad. However, only a limited number of such tests have been performed in which the loads were carried to complete failure.

TEST PROGRAM AND SPECIMENS

The first test program for portal frames includes three specimens, two of which have been tested. The physical details are shown in Table 1.

The members were chosen to agree closely with the

Table 1—Test Frame Dimensions

TEST FRAME	SPAN	COLUMN HEIGHT	LOADING	BEAM	COLUMN	CONNECTION TYPE	
1	14'	7'	⅓ pt.	8WF40	8WF40	8B	
2	14'	7'	⅓ pt.	8B13	8B13	8B	
3	TO BE SELECTED						

J. M. Ruzek is with C. F. Braun and Co., Alhambra, Calif., and K. E. Knudsen, E. R. Johnston and L. S. Beedle are with Lehigh University, Bethlehem, Pa.

Presented at the Spring Meeting of the Society for Experimental Stress Analysis in Indianapolis, Ind., May 1952, and published in Vol. VI, No. 1 of the Society's *Proceedings*.

previous test specimens of component frame parts. In an earlier program of continuous beam tests[5] a portal frame of the type shown in Fig. 1 was simulated by a 3-span continuous beam (span lengths 7, 14 and 7 ft).

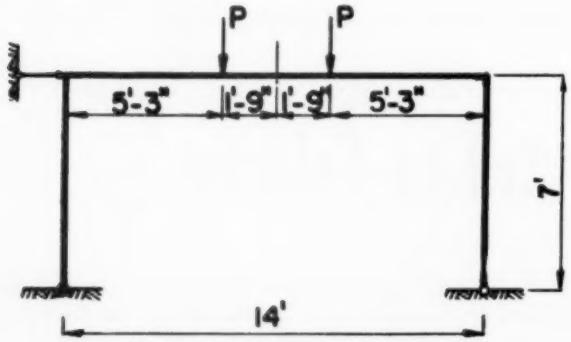

Fig. 1 Type of frame and loader

The effects of corner connections and of axial loads are absent in such simulated frame tests. In the previous connection test program the 8B13 section and the same corner connection types were used.

An over-all view of Frame 1 is given in Fig. 2. The welded corner connection type used in Frames 1 and 2 is shown in Fig. 3.

The loading consists of two equal concentrated vertical loads applied to the beam in the plane of the frame at points one-quarter of the span apart and symmetrical about the frame centerline. This $^3/_8$-point loading was selected to eliminate plastic failure due to shear force. This was not completely successful as some shear failure occurred in the beam near the corner connections of Frame 1 (Figs. 2 and 3).

Since side-sway and lateral buckling of the beam would cause undesirable complication of the analysis of these introductory tests, such factors were excluded by providing both longitudinal and lateral supports as described in the following. The testing equipment was designed with sufficient capacity to develop the full plastic hinge moments of the rolled section.

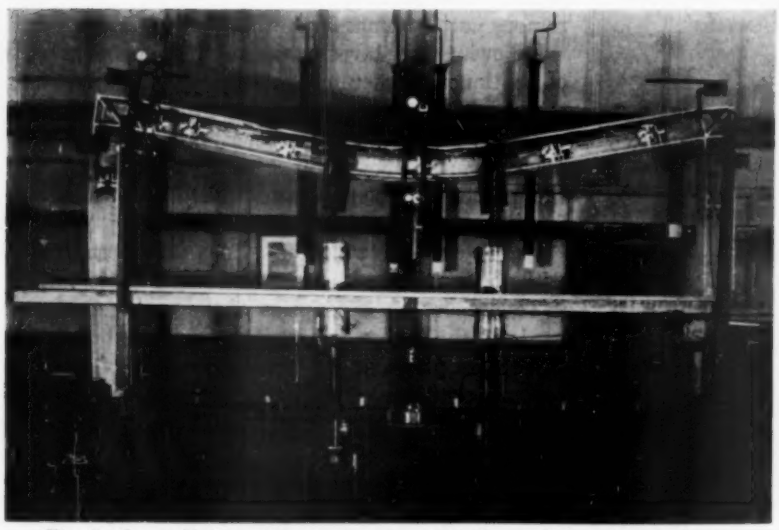

Fig. 2 Over-all view of test apparatus with Frame 1 tested to collapse

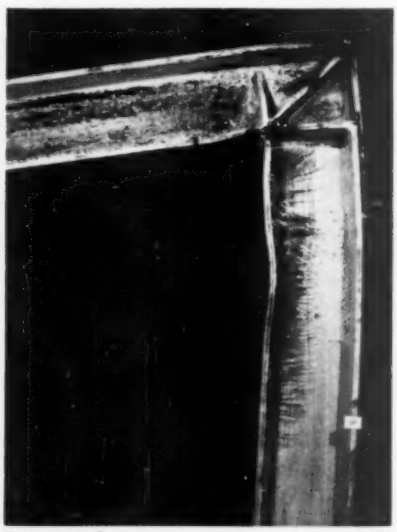

Fig. 3 Corner connection Type 8B after collapse of frame

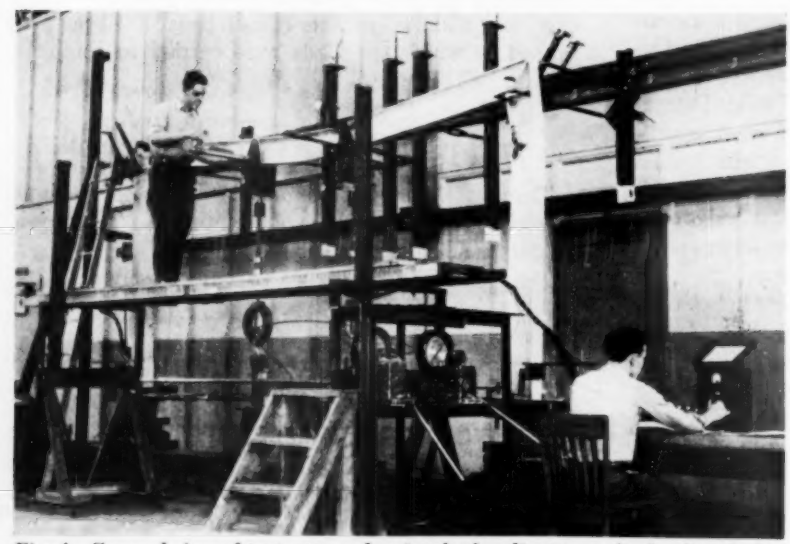

Fig. 4 General view of test setup, showing hydraulic pumps for loading jacks, and SR-4 strain indicator

DESCRIPTION OF TEST APPARATUS

General views of the test apparatus with a test frame in position are shown in Figs. 4 and 5. The main parts of the test apparatus are described in the following paragraphs.

Column Supports

The frame columns are welded to heavy base plates (Fig. 5), which rest

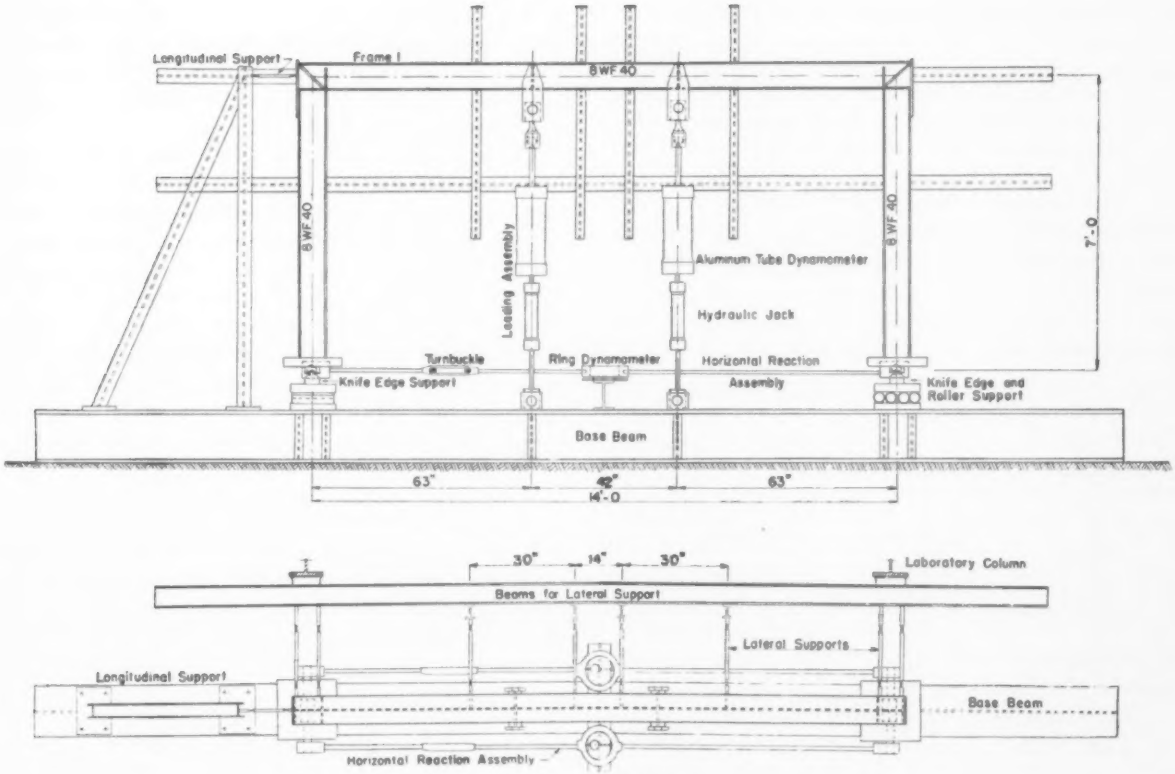

Fig. 5 Test setup

on knife-edge supports. Longitudinal movement of the support points is not allowed but rollers are provided at one support. The distance between supports is held constant by means of the horizontal reaction assembly which also makes possible the measurement of the horizontal reaction.

Horizontal Reaction Assembly

On each side of the heavy column base plates pinned connections are provided near the axis of the knife-edge supports for two round-bar ties which extend between the ends of the columns as shown in Fig. 6. In the side view of the test apparatus, Fig. 5, only the far tie is shown. The longitudinal distance between supports as indicated by the dial gages, Fig. 6, is maintained constant throughout the test by means of turnbuckles. Ring dynamometers, one on each tie and supported on three steel balls, enable the measurement of the hori-

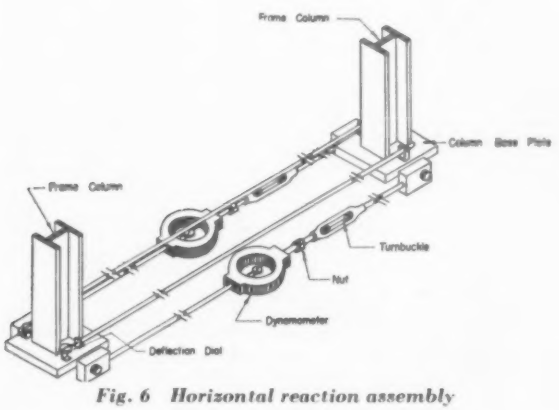

Fig. 6 Horizontal reaction assembly

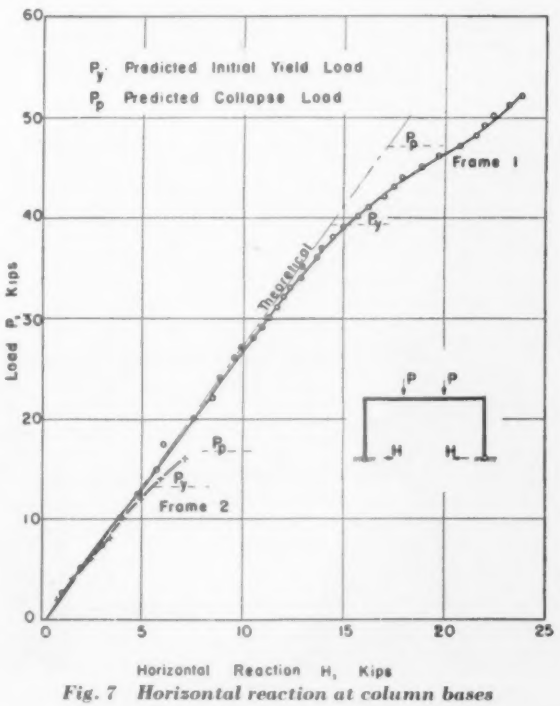

Fig. 7 Horizontal reaction at column bases

zontal force. In Fig. 7 this measured reaction is plotted versus the corresponding load on the frame beam.

Longitudinal Support

Side-sway is prevented by a longitudinal support at one frame knee as shown in Fig. 5. The support is provided by a round flexible bar welded to the frame. The cross section is reduced near both ends to eliminate undesirable restraints. The same basic type of bar is also used for the lateral supports described hereafter.

Lateral Supports

As indicated in Fig. 5, lateral support is provided at four points along the frame beam in locations where severe plastic straining is expected. In addition, the corner connections are held laterally at the top and bottom points of the diagonal stiffener. Earlier separate tests of corner connections[4] indicated the necessity of securing both these points.

The large deflections of the frame beam in the plastic range would cause an appreciable slope in the lateral supporting bars if means of vertical adjustment were not provided. The resultant force would pull the frame out of alignment. A method was developed to provide for adjusting these bars and is shown in Fig. 8. The corners of the frame do not deflect appreciably, and no vertical adjustment of lateral support is needed at these points (Fig. 9). (The right-hand connection for the corner bars as shown in this figure is too flexible; the bars should have been welded directly to the I-beam.)

During testing the lateral support rods were adjusted at intervals so that their fixed ends were 1 in. below the ends connected to the frame. A further deflection of 2 in. of the frame beam at the point of lateral support could then be tolerated before a new adjustment became necessary. The extreme horizontal deflection of the frame due to slope of these bars is less than 0.002 in.

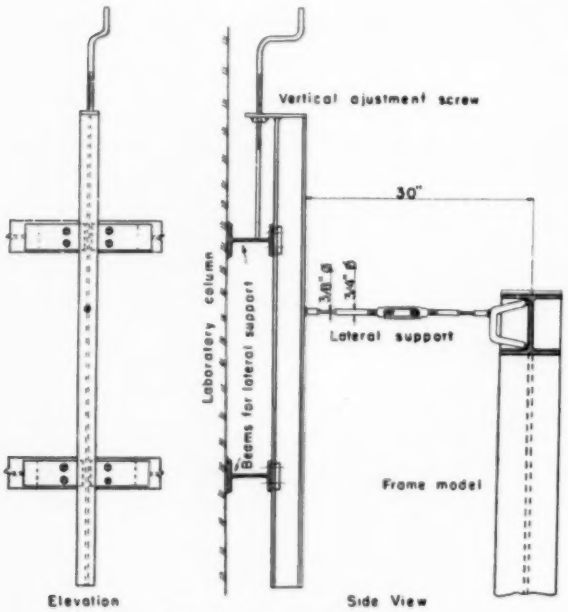

Fig. 8 Lateral support

Loading Assemblies

Loads were applied to the frame beam by means of manually operated hydraulic jacks. Aluminum tube dynamometers of 100 kips capacity were used for load measurement on Frame 1 (8WF40 shape). For Frame 2 (8B13 shape) the expected maximum loads were appreciably smaller, and ring dynamometers of 30,000-lb capacity were used as shown in Fig. 10.

The concentrated loads were transferred to the frame beam through load carriers welded to the beam web and flanges as described in Reference 1. The loading assemblies are pin-connected to the load carriers at the top and to the base beam at the bottom (Fig. 5). A spheri-

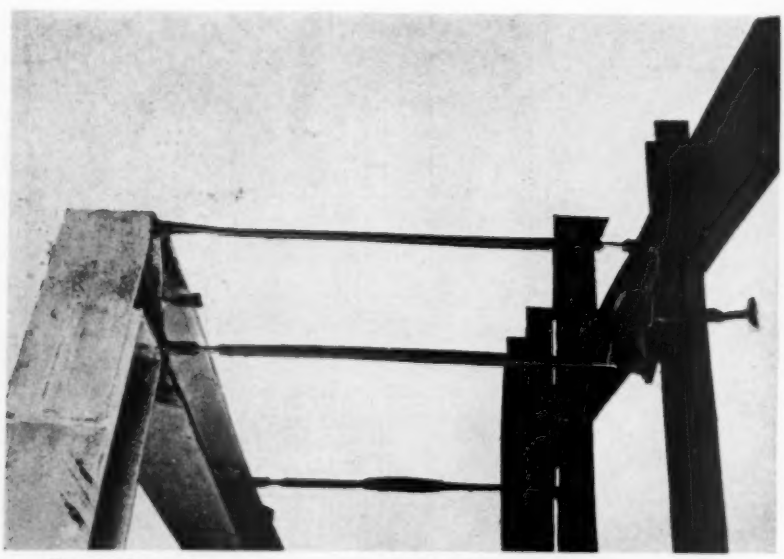

Fig. 9 Lateral support at corner connection and along frame beam

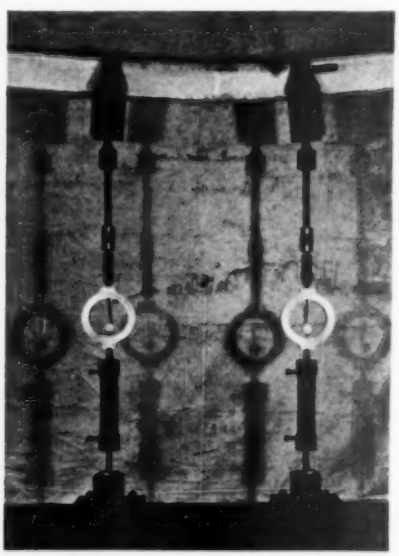

Fig. 10 Loading assemblies for Frame 2. Hydraulic jacks and ring dynamometers

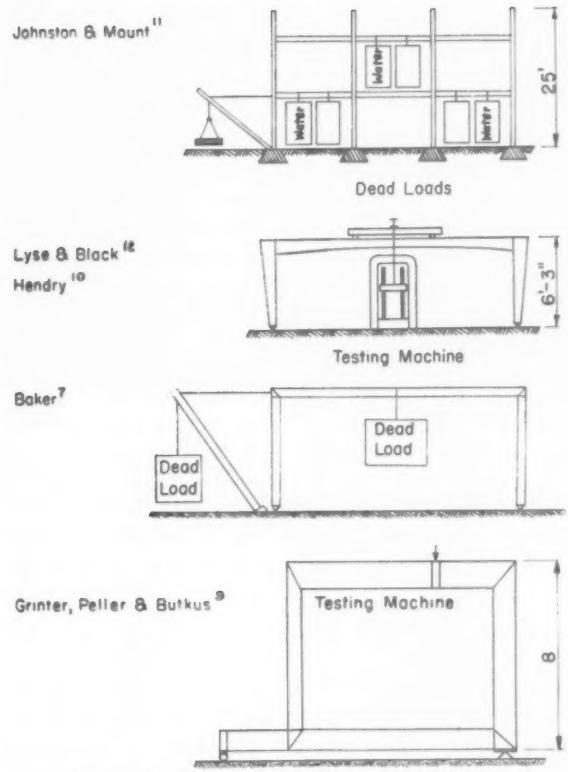

Fig. 11 Loading schemes used in frame tests

of a testing machine usually limits the frame size or type of loading that may be applied The use of hydraulic jacks is advantageous for testing full-size frames to determine ultimate strength and load deformation relationships beyond the maximum load.

Longitudinal Loading Device

In a future test program, it is planned to investigate the effect of combined vertical and side loading in the plane of the frame. The side loading would be applied as concentrated third-point loads on one column with a direction causing compressive axial load in the frame beam. This loading is somewhat more difficult to achieve in the laboratory than a simple tensile force applied along the extension of the beam axis, as used in the earlier tests (Fig. 11).[7, 11] However, the difference between these two methods of producing side-sway is important. Application of a tensile force will superimpose tensile stresses across the beam section. In contrast, application of a compression load on the windward side is more realistic since it simulates the actual condition of side-sway caused by wind or blast forces and results in an added compressive stress in the beam which would cause it to buckle laterally at a lower load.

For inclusion of side-sway in future frame tests, the test apparatus may be altered as indicated in Fig. 12. The vertical loading assembly would be adjusted at each load increment to maintain its vertical position.

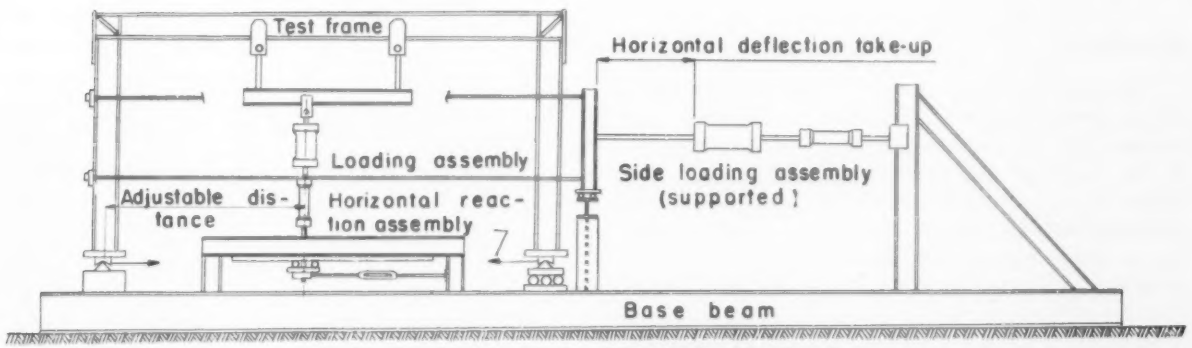

Fig. 12 Combined vertical and longitudinal loading device

cal bearing inserted between the dynamometer and the frame further ensures pure tension in the loading assemblies and simplifies the procedure for aligning the frame prior to test.

The maximum stroke of the hydraulic jacks is 12 in. In Frame 1 resetting of the jacks was necessary since the test was carried on to a center deflection of more than 13 in. On the second test only about half of one stroke was required to bring about collapse.

Loading schemes used in other frame tests (7, 9–12) are pictured in Fig. 11. The use of dead loads precludes a study of frame behavior at deflections greater than that at the maximum load since the assembly collapses when the maximum load is reached. The use

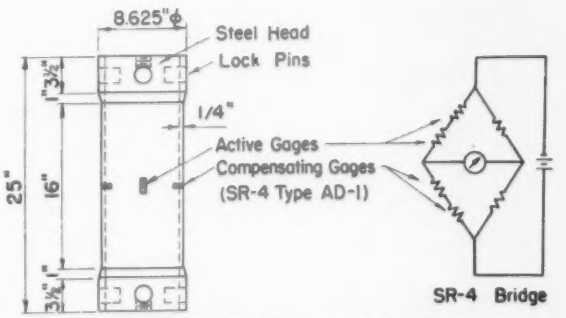

Fig. 13 100-kip aluminum-tube dynamometer

The same horizontal reaction assembly as described previously would be used to measure the horizontal reaction at the roller-supported column base. By subtracting this reaction from the total horizontal load applied, the other horizontal reaction at the anchored support may be found.

MEASUREMENT TECHNIQUES

Dynamometers

As indicated above, ring dynamometers fitted with dial gages were used to determine the applied loads on Frame 2 (Fig. 10), and to measure the horizontal reactions in both tests (Figs. 2 and 5). The Bourdon tube pressure gages attached to the hydraulic pumps were used only as a rough check on the applied loads.

The expected magnitude of loads on Frame 1 (P_{max} = 55 kips) was greater than the capacity of the available ring dynamometers. Dynamometers of 100 kips capacity were fabricated from $8^1/_2$-in. diam 61S-T6 aluminum tubing (Figs. 2 and 5). The details of the tube dynamometers are shown in Fig. 13. These dynamometers, designed for the tests reported in Reference 5, are similar to those described in an earlier Progress Report.[2] Four SR-4 strain gages, Type AD-1, are mounted on each tube in an arrangement which eliminates the effects of temperature variations and cancels any bending stress. A similar application of SR-4 strain gages on aluminum torque meters is described in Reference 8.

Deflections

Deflections along the beam and columns were measured at locations shown in Fig. 14. Dial gages ($^1/_{1000}$) were mounted on a stiff deflection dial bridge supported on the frame at the intersections of the beam and column axes. At one connection the bridge rests on a knife-edge support (Fig. 14, Detail "*A*"). At the other knee a roller support is provided (Fig. 14, Detail "*B*") to allow for shortening of the beam during the test. Vertical deflections of the beam are thus measured relative to a line connecting the frame corners; column deflections are measured relative to the longitudinally fixed knee.

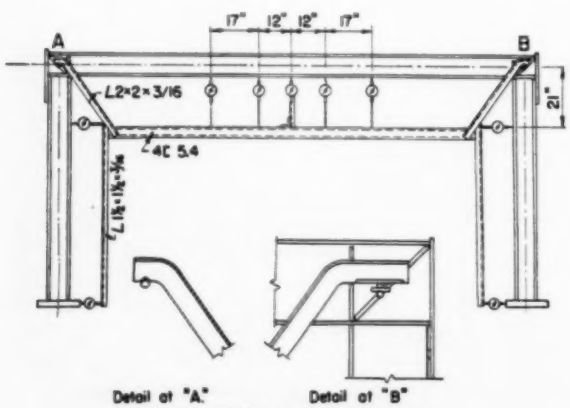

Fig. 14 Deflection dial support

Local Buckling of Flange

Dial gages were mounted between flanges at critical locations (Fig. 15) to indicate flange buckling. Figure 15 also shows details of a "local buckling dial gage" in use. In the later stages of the test the deformation becomes quite pronounced, an example of which is shown in Fig. 3.

Rotations

Figure 16 gives the typical locations of these measurements. The rotations of cross section at the various points along the frame are measured by level bars of the type shown in Fig. 17. The level bars are attached to the frame by means of brackets of the same type as used for the lateral supports, Fig. 8, the effect of shear distortion in the web being eliminated by welding the

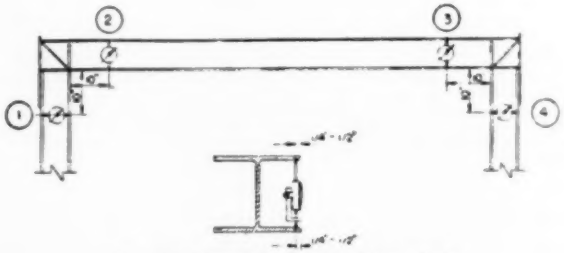

Fig. 15 Local flange buckling dials

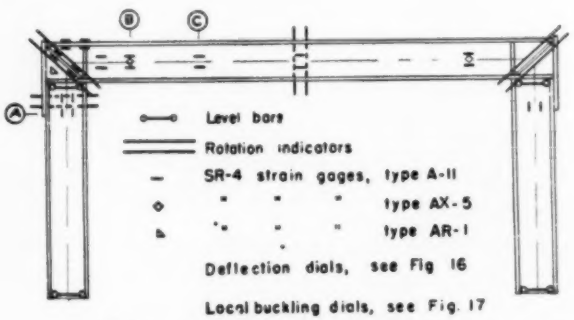

Fig. 16 Location of gages on Frame 2

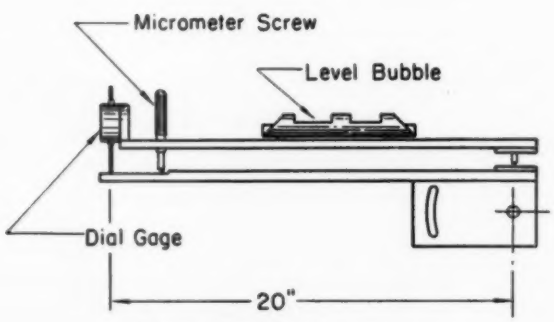

Fig. 17 Level bar

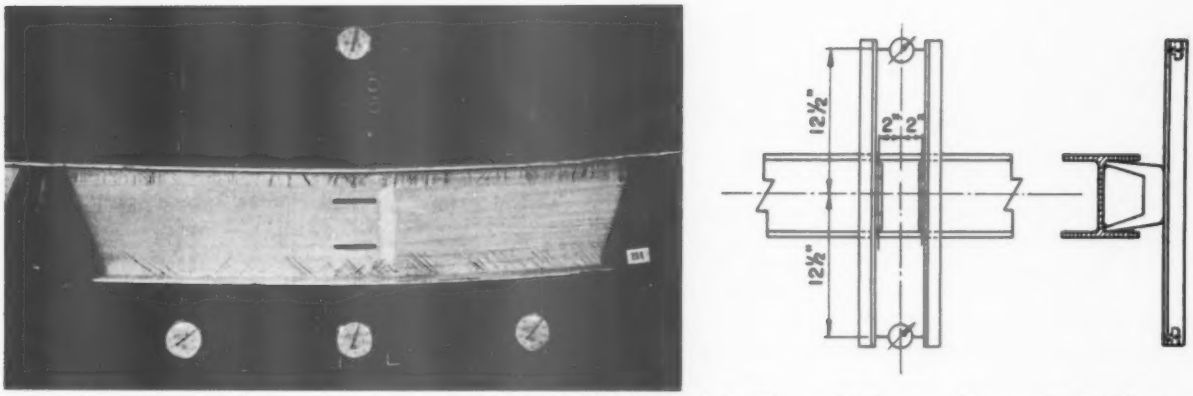

Fig. 18 Three means of measuring curvature: (a) Three deflection dials, (b) two SR-4 gages, (c) a rotation indicator

brackets to the flange-web fillets. This method of attachment also gives the best average of the cross-section rotation due to bending.

Curvature

For purposes of structural analysis it is important to know the relation between the moment M and the angle change ϕ, for a unit length of member. From this $M - \phi$ relationship, slopes and deflections may be computed both in the elastic and the plastic range. The direct measurement of the curvature ϕ is therefore an important part of the experimental investigation.

The center portion of the frame beam is subjected to a uniform moment. The curvature ϕ at the centerline has been determined in the past by three different methods:

1. Deflection readings from three dial gages (Fig. 18).
2. Data from SR-4 strain gages mounted above and below the neutral axis of the beam.
3. Change in slope as determined by means of two level bars.

For several reasons it was desirable to improve this technique. Method 1 is often insensitive in the elastic range, and for dependable results it requires that a considerable length of the member be under uniform moment. Method 2 gives a rather localized picture of the $M - \phi$ relationship, is expensive in use of SR-4 gages and, unless post-yield gages are used, does not provide an adequate range of measurement.

A device called a rotation indicator was therefore developed to measure the relative rotation of two neighboring cross sections. This device may be used repeatedly on successive tests and for installation only requires the welding of the attachment device to the specimen. This rotation indicator is pictured in Fig. 18. It consists of two parallel steel lever arms rigidly welded to the beam at the fillets and symmetrically placed on each side of the section at which the curvature is to be measured. Brackets similar to those used for lateral support and described above, Fig. 8, joined the lever arms to the beam. The relative rotation of these arms is measured by means of two dial gages mounted at a known distance ($12^1/_2$ in.) above and below the frame axis. The curvature of the beam between the arms equals the measured angle divided by the distance (4 in.) between the two arms. Denoting the simultaneous dial reading differences, as R_1, and R_2, respectively, the curvature ϕ is given by

$$\phi = \frac{R_1 - R_2}{4 \times 25} = 0.01(R_1 - R_2).$$

The curvature as measured by this rotation indicator is sensitive to about 10^{-5} radian or 2 sec, which is quite sufficient for all practical purposes.

A comparison of results obtained by using the four

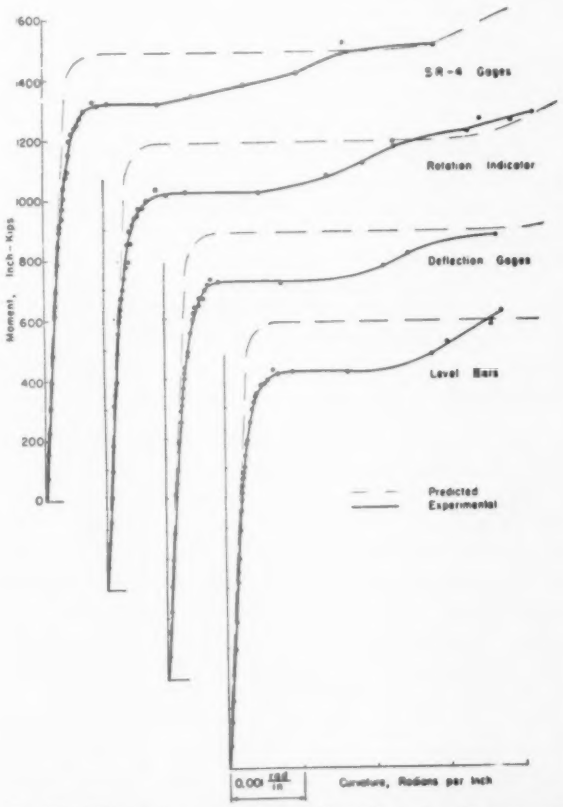

Fig. 19 Moment-curvature relationship at mid-span of beam, Frame 1

methods for determining ϕ is given in Fig. 19. The four methods give results which agree closely. The rotation indicator provides the largest range of rotation and the dials may be reset if necessary. The predicted $M - \phi$ relationship as shown in Fig. 19 includes the effect of strain hardening, but neglects the effect of axial load.

The rotation indicator will also give satisfactory results at sections where the moment has a gradient, and also in regions of strain hardening. While the strain-gage technique may also be used under these conditions, Method 1 is not feasible.

Another function of the rotation indicator is to measure the rotation in the connections. In the past this has been accomplished with the aid of level bars,[4] a procedure that was also used on Frame 1. On Frame 2, however, rotation indicators were used on both corner connections, replacing the level bar technique (Fig. 16). The rotation indicator is attached to the end of the beam and the top of the column, adjacent to the connection using the same brackets as were previously used for level bar supports. The indicator thus extends across the connection and measures the total rotation due to shear and moment.

Strains

Strains were measured by means of SR-4 gages, typical locations being indicated in Fig. 16. Many gages were used on the corner connection to determine (1) the thrust transmission from flange to web and (2) the shear stress carried by the web compared to direct stress in the stiffeners. These readings will provide comparison with the previous tests of corner connection.[4]

As noted above, A-11 type gages in pairs at points 2 in. on either side of the frame axis yielded information on the curvature of the beam and the columns at various points.

TESTING PROCEDURE AND REPRESENTATIVE RESULTS

Test Setup

After erection of the test frame on the knife edges and roller bearings, attachment of the longitudinal and lateral supports to the frame, and mounting of loading assemblies and the horizontal reaction assembly, a set of zero readings was taken on all deflection dials, local buckling flange dials, level bars, rotation indicators and strain gages. The initial readings of the horizontal dial gages shown in Fig. 6 which indicate the distance between column bases are the basis for maintaining a constant distance between supports. After each load increment the turnbuckles were used to return the column base mounted on rollers to its initial position. The test thus simulated a pin-end condition, and the loading and moment diagram for the frame is as shown in Fig. 21.

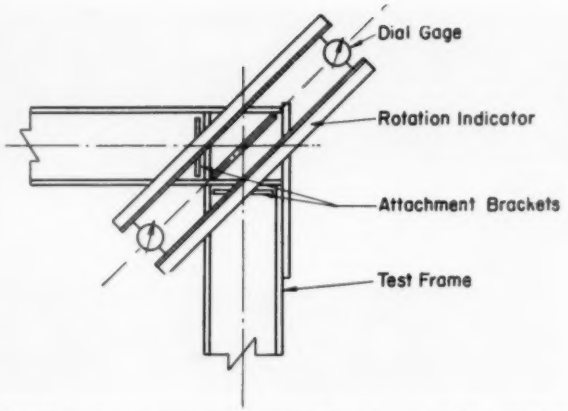

Fig. 20 Corner connection rotation measured by rotation indicator

If simply supported, the frame beam of Fig. 21 would experience a maximum moment of

$$M_s = {}^3/_8 PL \qquad (1)$$

The horizontal reaction H at the column bases causes a restraining haunch moment

$$M_h' = Hh_1 \qquad (2)$$

and the net beam moment between load points is:

$$M_b' = M_s - M_h' = {}^3/_8 PL - Hh_1 \qquad (3)$$

The horizontal reaction H is carried by the beam as an axial compressive force. In the plastic range the

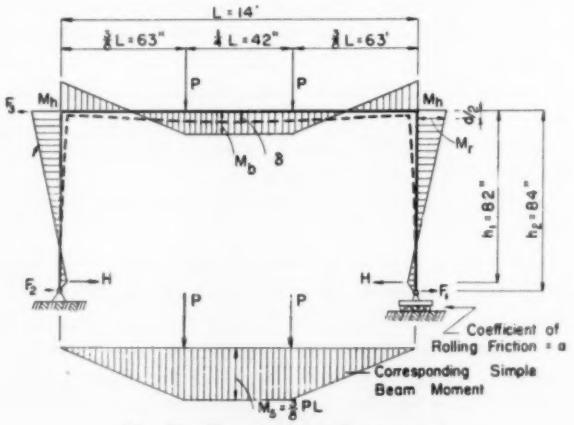

Fig. 21 Test loads and moments

beam deflection δ becomes large and the additional beam moment due to this axial force

$$M_h = H\delta \qquad (4)$$

can no longer be neglected. The magnitude of this correction, in percent of the total moment at the beam (Frame 1) is:

0.6% at $\delta = L/360$,	P = 26k,	δ =	0.5 in.
1% at calculated yield load,	P = 39k,	δ =	0.9 in.
11% as shown in Fig. 22 for	P = 50k,	δ =	7.2 in.
20% at the ultimate load,	P = 55k,	δ =	12.4 in.

A correction may also be considered due to the friction force αP at the roller base, where α is the coeffi-

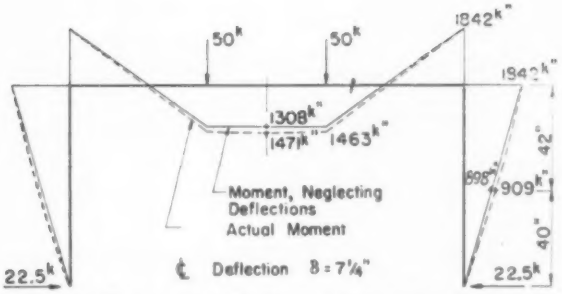

Fig. 22 Influence of deflection on the moment distribution, Frame 1

cient of rolling friction. The haunch moment eq. 2, corrected for this influence, becomes (Fig. 21),

$$M_h = Hh_1 - \alpha Ph_2 \qquad (5)$$

The value of α can be taken as 0.01*, and its effect on the critical moments at the haunch and the beam center is then between 2.3 and 3.0%. An error in the assumed value of α will therefore be of small consequence.

The maximum moment in the beam including the effect of beam deflection and roller friction, neglecting the small product $\alpha \cdot \delta$, finally becomes

$$M_b = M_s - M_h + (H - \alpha P)\delta = P\,(^3/_8 L + \alpha h_2) - H(h_1 - \delta) \qquad (6)$$

At the knee, the critical moment occurs in the beam or the column next to the comparatively rigid corner connection. For the loading and proportions of these frames the critical section is in the column at a distance $d/2$ from the theoretical corner (d = depth of the rolled section). From eq. 5 this moment M_r is given by

$$M_r = H\left(h_1 - \frac{d}{2}\right) - \alpha P\left(h_2 - \frac{d}{2}\right) \qquad (7)$$

As the test is carried into the plastic region, yielding must be expected to develop due to these two critical moments M_b and M_r, eqs. 6 and 7. The $^3/_8$-point loading, dictated by the consideration of avoiding plastic shear failure, caused the center moment to be the larger of the two. In the absence of residual stresses and stress concentrations, plastic deformation would therefore first occur in the center portion of the beam and would be followed by plastic deformation near the top of the columns. Since both stress concentrations and residual stresses were present, location of the first yield line would probably not follow the predicted pattern. Ultimately, however, significant plastic deformations would be expected both at the center portion of the beam and at the haunches. This behavior was verified by tests, as pictured in Figs. 3 and 23.

* 0.005 for each contact surface. See Marks' *Mechanical Engineering Handbook*, 5th ed., p. 223 (1951).

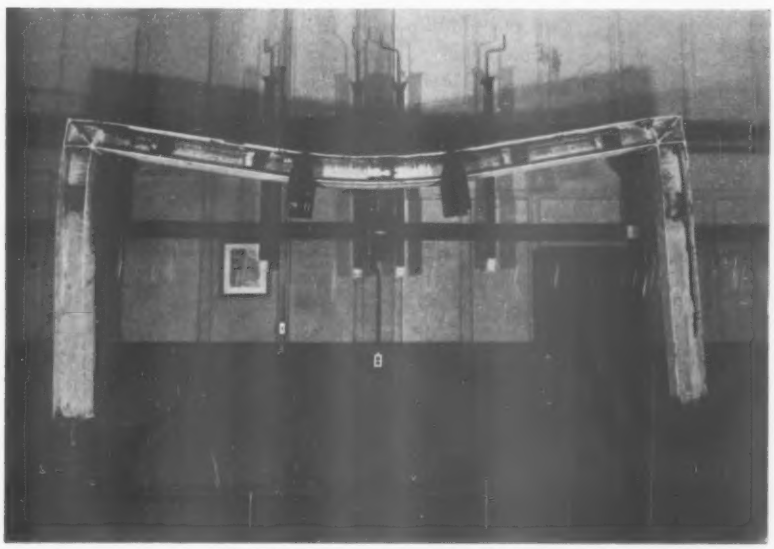

Fig. 23 Frame 1 tested to failure

Testing Procedure

After frame alignment was completed and before the actual test was run, a "friction test" was performed, the purpose of which was to give a check on the complete test setup. Readings on all gages were taken during a loading up to about one-third of the load calculated to give initial yield. The observed deflections, rotations, etc., were plotted in comparison with the corresponding theoretical curves; discrepancies would indicate the need of further alignment of the frame or adjustment of the gages.

The main test was then carried out. In the elastic range, load was applied simultaneously at the two load points until the dynamometers indicated the desired load. The horizontal translation of the roller support during load application was then eliminated by means of the turnbuckles on the horizontal reaction assemblies, and the necessary readings, photographs and yield line sketches were taken. Due to stress concentrations and residual stresses, local yield was expected and did occur at loads below the theoretically predicted initial yield loads.

The initial load increments for Frame 1 were 2.5 kips or 10% of the load expected to cause initial yield. After yielding had occurred, the increments were reduced to 1.0 kips, or 2% of the ultimate load. For the weaker Frame 2, load increments of 0.5 kip were applied throughout, corresponding to about 4% of the initial yield load.

In the plastic range appreciable deformations take place under constant load for some time after the application of a load increment. This is due to the penetration of yielded zones ("wedges") into the specimen. A criterion is therefore needed to indicate when such plastic creep has ceased to be of importance, and when readings can be taken. The adopted criterion was as follows: When the increase of deflection of the frame centerline over a 15-min period was no greater than 0.0015 in., it was assumed that suffi-

ciently stable conditions had been reached, and readings were taken. Curves showing the increase in center deflection under constant load are plotted for various load increments in Fig. 24. This criterion was selected on the basis of previous experience with continuous beam tests employing the same cross section and involving similar moment distribution. It appears to be adequate also in these frame tests. With the adoption of this criterion, however, a considerable amount of time was required for performance of each test. This may be seen from Fig. 24.

The possibility of reducing the criterion requirement without introducing appreciable experimental error is of interest. For the present, the selection of the criterion is rather arbitrary, being selected for each particular member. In each case, the criterion to be adopted will be a function of the length of member yielding, the type and size of cross section and length of span. The attainment of a general criterion applicable to a variety of conditions will require further study.

After the maximum load was reached the test was continued through larger deformations in order to study the effects of excessive rotation at critical sections and to observe the ability of the frame to deform and at the same time to carry an appreciable percentage of the maximum load. For example, the energy absorption is an important factor in studying the response of structures to blast loading. There is an obvious difference

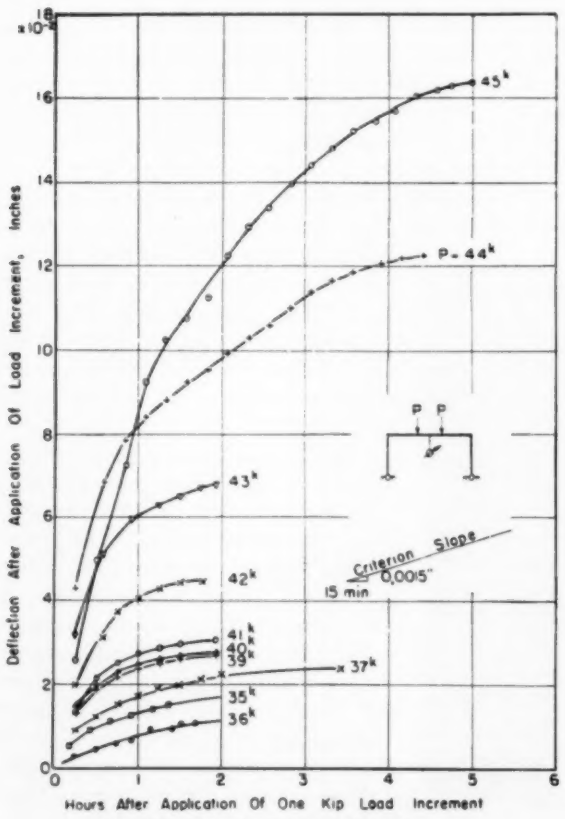

Fig. 24 Criterion deflection, Frame 1

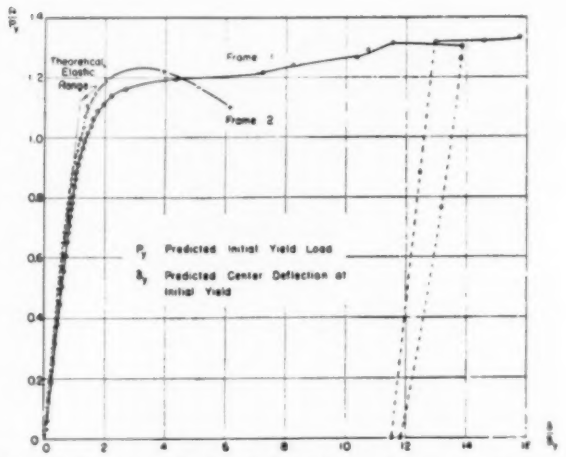

Fig. 25 Comparative load-deflection relations for Frames 1 and 2

in behavior of the two frames whose load-deflection relationships are plotted in Fig. 25.

Experimental points on the "unloading" portion of the load-deflection curves are determined by deforming the frame until a predetermined centerline deflection has been reached. After allowing the frame to come to equilibrium, readings of load and deflection were then obtained. This procedure is being followed currently on tests at the Fritz Laboratory, deformation of the structure being increased until the load has dropped below about 70% of the maximum value recorded during the test.

Test Results

A report of test results and analysis will be presented in a separate article. Only a few representative results related to the testing technique are presented here.

The frame tested is statically indeterminate to the first degree. By measuring the horizontal force applied to each column base, the test frame becomes determinate, and statics may be used to determine the moment distribution. However, in more complicated types of frames it may not be possible to measure all reactions, with the result that the frame as tested may also be indeterminate.

The question of interest to the experimenter is as follows: with what accuracy may the distribution of stresses around the frame be predicted on the basis of measurements of strains, rotations and deflections? It is probable that little difficulty would be experienced in the elastic range. However, in the plastic range the measured relationship between moment and deformation in as-delivered steel members does not correlate well with available theory.[5]

It therefore seems that the strains, rotations or deformations from which the stress distribution around the frame would be deduced should be measured on parts of the frame which remain in the elastic range throughout the test. If forces and moments can be

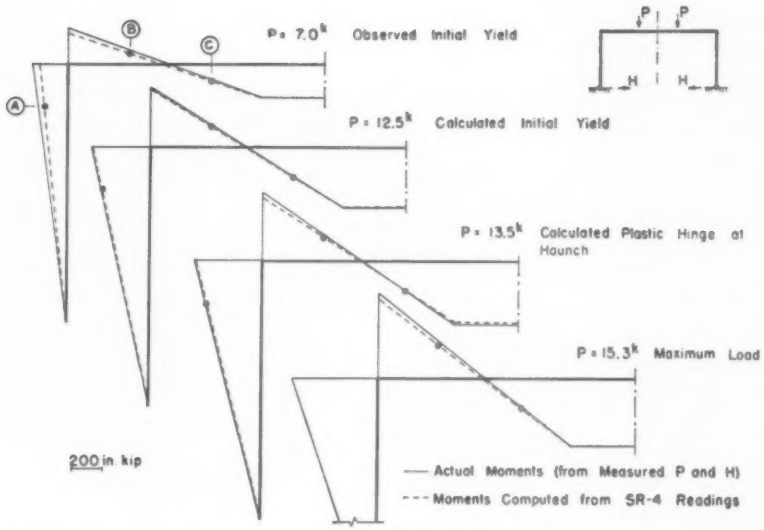
P = 7.0k Observed Initial Yield
P = 12.5k Calculated Initial Yield
P = 13.5k Calculated Plastic Hinge at Haunch
P = 15.3k Maximum Load
200 in. kip
Actual Moments (from Measured P and H)
Moments Computed from SR-4 Readings

Fig. 26 Experimental moments determined from load measurements and from strain readings

predicted from the above-mentioned measurements alone, then more complicated frames may be tested with assurance that the measurements would afford some means of explaining the behavior observed.

As a partial answer to this question, the moment distribution around Frame 2 is calculated on the basis of SR-4 strain gage readings at locations *A*, *B* and *C*, Fig. 16. These strain gages remain in the elastic range throughout the test. Each pair of these gages permits the determination of curvature at the corresponding frame cross section, from which the moments are computed as shown by dotted lines in Fig. 26 for four load levels durjng the test. These moments agree well with the actual moment distribution as determined from the applied loads P and the measured horizontal reactions H. Thus, the moment distribution could have been determined with sufficient accuracy without measuring H.

A similar evaluation of the axial force in the members from the SR-4 strain gage readings gave a poor agreement with the actual values. This deficiency is ascribed to the fact that both gages in all the pairs (Fig. 16) were mounted on the same side of the web, thus including strain due to bending of the members about its weak axis. Such bending is introduced by the lateral support rods during deflection of the beam, and by possible eccentricity of the horizontal reaction assembly. In cases where the SR-4 gages would be depended upon also to indicate axial forces they should be mounted in pairs on both sides of the web.

Figure 19 shows the relation between the moment M and the curvature ϕ at the mid-point of the beam. The four curves, as mentioned earlier, correspond to the four different methods of measuring ϕ. Following the proportionality between moment and curvature in the elastic region, the curvature increases greatly in the plastic range with practically no increase in moment until strain hardening occurs and causes further increase in moment-carrying capacity of the section. The predicted M - ϕ relationship shown in Fig. 19 neglects the effect of axial load.

Figure 27 shows the deflection at mid-span of the beam as a function of the load P for Frames 1 and 2. The calculated and the observed initial yield loads are indicated. Both frames demonstrate an appreciable reserve strength above this load.

SUMMARY

A testing technique is described for investigating the behavior of full-size welded portal frames (Fig. 1) through the elastic and plastic range to collapse.

The frame tests described are part of an investigation of welded continuous frames and their components.

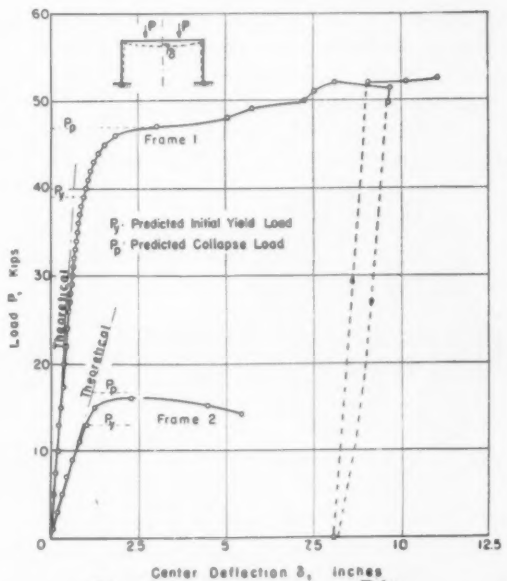

Fig. 27 Deflection at mid-span

The complete results of the tests will be presented in a paper now in preparation. This report describes and evaluates testing methods and equipment as summarized hereafter:

1. The test setup (Fig. 5) and the technique used for measuring deflections (Fig. 14), slopes (Fig. 17), curvatures (Fig. 18), strains (Fig. 16) and loads (Figs. 6, 10 and 13) are described in detail. The performance of the test equipment proved satisfactory.

2. The loading device (Fig. 10) made it possible to apply loads through the elastic and plastic range and also to determine the load-deformation relationship beyond the maximum load.

3. The scheme shown in Fig. 12 is recommended for tests including side loading.

4. A rotation indicator (Fig. 18) used for the first time in these tests allows the measurement of curvature of structural members and may also be used to determine corner connection rotations (Fig. 20). This device has a larger range, is simpler and more economical in use than combinations of deflection dials, level bars or SR-4 gages.

5. The distribution of moment around the test frames may be predicted with satisfactory engineering accuracy by means of SR-4 gages mounted on parts of the frame which remain in the elastic range throughout the test (Fig. 26).

6. Representative results from the test of the two full-size portal frames are shown in Figs. 7, 19, 25 and 27.

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Literature Survey on High-Strength Steels

◗ *Addendum to information published by Subcommittee of Pressure Vessel Research Committee*

DURING preparation of the original survey by the Subcommittee on Research on High Strength Steels of the Materials Division, PVRC, it was decided to include in the tabulation only those proprietary high-strength low-alloy steels that would meet a requirement of 50,000 psi yield point, minimum, in plate thicknesses of $^1/_2$-inch or over. After the table appeared in the May 1954 issue of the WELDING JOURNAL RESEARCH SUPPLEMENT, attention was called to an omission from the published information.

Therefore, the following should be considered part of the original tabulation:

Trade name or designation	Mayari-R
Composition, %	
C	<0.12
Mn	0.50/1.0
Si	0.10/0.50
P, max.	0.12
Cr	0.40/1.0
Ni	0.50/1.00
Cu	0.20/0.50
Manufacturer	Bethlehem Steel Co.
Yield point or yield strength, psi.	>50,000
Tensile strength, psi.	>70,000
Dimensions (max. plate thickness), in.	4
Heat treatment	As-rolled
Endurance limit, psi.	42,000
Weldability	Weldable
Recommended electrode	Mild steel

As indicated in the original presentation, most of the proprietary high-strength low-alloy steels covered by the survey are available only in structural quality. Before they are considered for pressure vessel construction, particularly when the wall thickness equals or exceeds $^1/_2$-in., the steel producer should be consulted.

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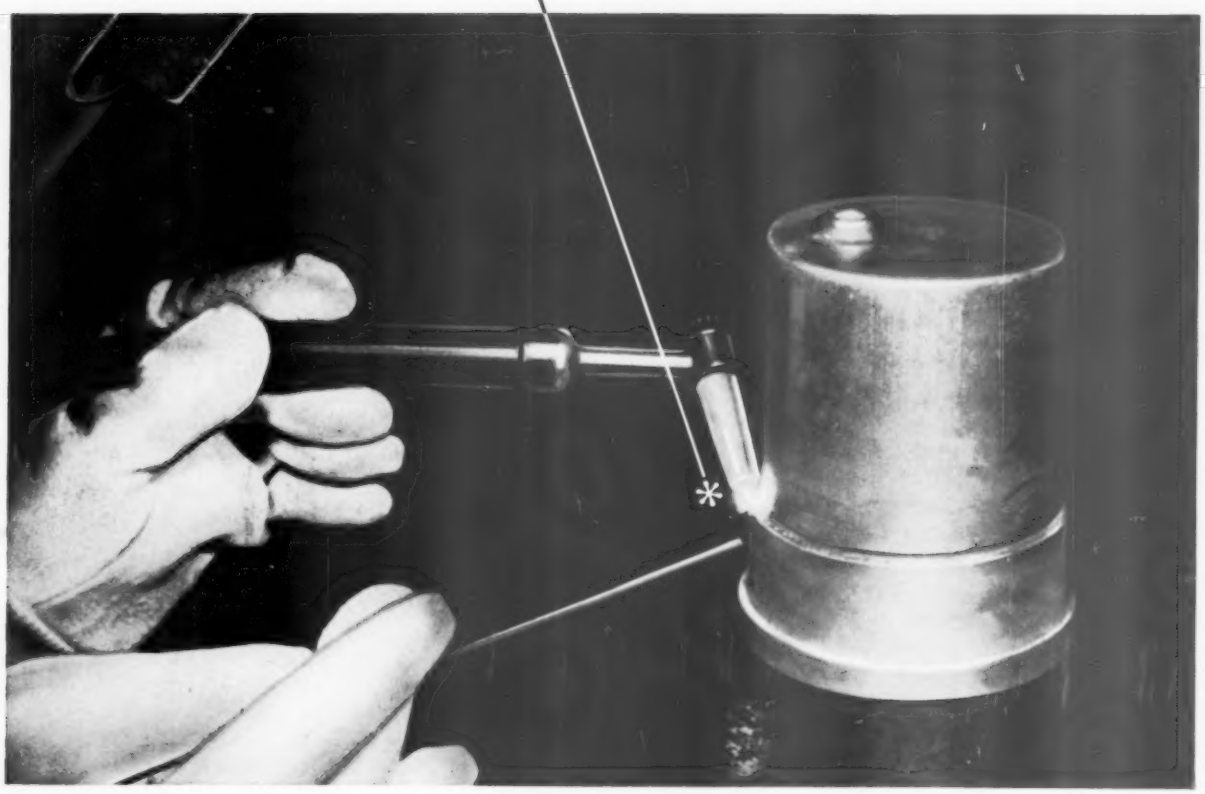

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